BENCHMARK WORKSHOP ON THE DEVELOPMENT OF MSY ADVICE FOR CATEGORY 3 STOCKS USING SURPLUS PRODUCTION MODEL IN CONTINUOUS TIME; SPICT (WKMSYSPICT)

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ICES International Council for the Exploration of the Sea
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i Executive summary

A unique feature of the Benchmark Workshop on the application of SPiCT to produce MSY advice for selected stocks (WKMSYSPiCT) was the model learning sessions, carried out prior to the data evaluation meeting. Thirteen stocks, including nine demersal fish stocks and four Functional Units of *Nephrops* (*Nephrops norvegicus*), pertaining to four ICES Assessment Working Groups (WGNNSSK, WGDEEP, WGCSE and WGBIE), were selected for the benchmark based on the availability of appropriate data and capacity. Stock assessments using the Surplus Production in Continuous Time (SPiCT) were successful for two demersal stocks, Megrim (*Lepidorhombus spp*.) in Division 6.b (lez.27.6b) and Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (ank.27.8c9a) and for three Functional Units of *Nephrops*, Norway lobster FU 25 (nep.fu.25), Norway lobster FU 26–27 (nep.fu.2627) and Norway lobster FU 31 (nep.fu.31). WKMSYSPiCT considered that these stocks could be upgraded from category 3 to category 1 since the methodology is appropriate to determine stock status and for short-term catch forecast. Several model configurations were applied for the two Tusk (*Brosme brosme*) stocks, Tusk in subareas 1 and 2 (usk.27.1-2) and Tusk in subareas 4 and 7-9, and in divisions 3.a, 5.b, 6.a, and 12.b (usk.27.3a45b6a7-912b) and for Norway lobster FU 28–29 (nep.fu.2829) but the available data did not allow to distinguish between two very different stock status. For Pollock (*Pollachius pollachius*) in Subarea 8 and Division 9.a (pol.27.89a), no model configuration passed diagnostics tests. The extensive exploration of input data and model configurations carried out during the workshop resulted in several recommendations regarding the use of historical catches, the standardization of CPUE, including approaches accounting for spatial, target and technological creep effects and, SPiCT model diagnostics.

ii Expert group information

Expert group name	Benchmark Workshop on the development of MSY advice for category 3 stocks using Surplus Production Model in Continuous Time; SPiCT (WKMSYSPiCT)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Manuela Azevedo, Portugal (ICES Chair)
	Massimiliano Cardinale, Sweden (External Chair)
Invited Experts	Casper Berg, Denmark
	Henning Winker, Italy
Meeting venue and dates	15–19 February 2021, Online meeting, 23 participants

1 Introduction

1.1 Terms of Reference

The Benchmark Workshop on the application of SPiCT to produce MSY advice for selected stocks (WKMSYSPiCT), co-chaired by Manuela Azevedo, Portugal (ICES Chair) and Massimiliano Cardinale, Sweden (External Chair), and reviewed by Casper Berg (Denmark) and Henning Winker (JRC, Italy), will meet by web conference: for two days in October 2020 for model learning sessions with SPiCT developers; 17–19 November 2020 for a data evaluation meeting, and; 15–19 February 2021 for the assessment workshop. WKMSYSPiCT will evaluate the appropriateness of data and the use of the Surplus Production in Continuous Time (SPiCT) to provide MSY advice for selected stocks. The specific ToRs for this workshop are:

1. Collate necessary data and information for the application of SPiCT for the stocks listed in Annex 1 prior to the data evaluation workshop.
2. Review the available data and make recommendations on the most appropriate series to be used for SPiCT and potential improvements to eliminate biases.
3. Apply the SPiCT methodology and determine the appropriateness of the data and the methodology to determine stock status for each of the stocks listed using the guidance developed following WKLIFEVII, WKLIFEVIII and WKLIFEIX.
4. For stocks where the methodology is appropriate, determine the methods to derive the parameters for the catch forecast using the harvest control rule for providing MSY advice using SPiCT.
5. Prepare the stock annex for those stocks where SPiCT is considered appropriate for providing MSY advice.
6. Develop recommendations for improving the guidance and training for the application of SPiCT and for deriving MSY advice.

The Benchmark Workshop will report by 5 March 2021 for the attention of ACOM.

The following thirteen stocks, including nine demersal fish stocks and four functional units of *Nephrops*, pertaining to four ICES Assessment Working Groups (WGNNSSK, WGDEEP, WGCSE and WGBIE), were selected for the benchmark:

- Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat) (dab.27.3a4);
- Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat) (fle.27.3a4);
- Tusk (*Brosme brosme*) in subareas 1 and 2 (Northeast Arctic) (usk.27.1–2);
- Tusk (*Brosme brosme*) in subareas 4 and 7-9, and in divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic) (usk.27.3a45b6a7–912b);
- Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall) (lez.27.6b);
- Cod (*Gadus morhua*) in Division 7.a (Irish Sea) (cod.27.7a);
- Sole (*Solea solea*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (sol.27.8c9a);
- Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (ank.27.8c9a);
- Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (pol.27.89a);

- Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and North Galicia) (nep.fu.25);
- Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (nep.fu.2627);
- Norway lobster (*Nephrops norvegicus*) in Division 9.a, Functional Units 28-29 (Atlantic Iberian waters East and southwestern and southern Portugal) (nep.fu.2829);
- Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay, Cantabrian Sea) (nep.fu.31).

1.2 Conduct of the Benchmark

The list of participants and the agendas for the data evaluation and the assessment benchmark workshop meetings are presented in Annex 1 and Annex 2, respectively.

To ensure credibility, salience, legitimacy, transparency and accountability in ICES work all contributors to ICES work are required to abide by the ICES Code of Conduct - CoI. The ICES CoI was brought to the attention of participants at the workshop and no CoI was reported.

A unique feature of the WKMSYSPiCT workshop were the learning sessions on the Stochastic production model in continuous-time (SPiCT) (Pedersen and Berg, 2017) during the mornings of 26th and 28th October 2020. The learning sessions were led by Casper Berg and Alexandros Kokkalis. Casper Berg presented the model properties and equations, main assumptions and data requirements. An example of SPiCT applied to the Eastern Baltic cod was used to highlight some features of the method. Alex Kokkalis introduced the new developments and features in SPiCT, which include a 'manage' function running default management scenarios, new function to compute Mohns´ rho and improved plot diagnostics, among other. A recommendation was made to always download the most recent version of SPiCT (code repository at https://github.com/DTUAqua/spict) prior to any SPiCT assessment trial run. Additionally, Henning Winker did a presentation on Just Another Bayesian Biomass Assessment (JABBA) (Winker *et al.*, 2018) and on the R package 'SPMpriors' which can be used for generating priors for stock assessments (e.g. parameter r in a Schaefer surplus production model) from 'FishLife' (Thorson *et al.*, 2017; Thorson, 2020).

Input data for SPiCT assessment runs were presented during the data evaluation meeting (17–19 November 2020) for each of the thirteen stocks listed above. Input data included landings/catch, survey and CPUE time-series. Preliminary SPiCT assessment runs were also presented and discussed. A list of tasks by stock (Annex 3) was determined aiming to improve the input data (e.g. CPUE standardization modelling, combining survey data) and the preliminary SPiCT runs (e.g. investigate the inclusion of survey information, the inclusion of historic catch data, different options for priors).

Aiming at an efficient and successful benchmark, it was agreed that participants would report on the work progress by 15th January 2021 and that the finalized working documents would be available to reviewers and participants by 1st February 2021, two weeks before the assessment benchmark meeting. However, only the following nine stocks have made available the working documents within the agreed deadline or with a time delay that was accepted by the chairs and were, therefore, considered for the assessment benchmark meeting (15–19 February 2021):

- Tusk (*Brosme brosme*) in subareas 1 and 2 (Northeast Arctic) (usk.27.1–2);
- Tusk (*Brosme brosme*) in subareas 4 and 7-9, and in divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic) (usk.27.3a45b6a7–912b);
- Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall) (lez.27.6b);
- Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (ank.27.8c9a);

- Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (pol.27.89a);
- Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and North Galicia) (nep.fu.25);
- Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (nep.fu.2627);
- Norway lobster (*Nephrops norvegicus*) in Division 9.a, Functional Units 28-29 (Atlantic Iberian waters East and southwestern and southern Portugal) (nep.fu.2829);
- Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay, Cantabrian Sea) (nep.fu.31).

The quality of the reviews has been affected by the late provision of some of the assessment draft documents with respect to the deadline set according to ACOM guidelines of submitting two weeks before the Benchmark. Of these, one has been delivered with one-week delay and two with a delay of four days. As a result, the reviewers had very limited time to review the assessments prior to the workshop. Despite of these delays, the reviewers and the external chair have made a lot of effort to still provide high quality revision of the documents and were able to provide detailed written feedback and recommendations prior to the meeting. On a very positive note, the stock assessors followed the recommendation to great detail and in some case beyond expectations. The presentations of the benchmark results were of high quality.

1.3 Reference points

The workshop followed the ICES guidelines for fisheries management reference points for stocks assessed with biomass dynamic models (ICES, 2017). In a surplus production model stock status evaluation and stock catch forecast options should be based on relative reference points. This is because the use of ratios reduces the variance in the estimated quantities of interest (QoI) and are thus likely to be much more stable when new datapoints are added compared to absolute estimates. In other words, if F_{MSY} is over-estimated then F is likely to be equally over-estimated, but this bias cancels out when using the ratios.

In addition, the reference points are re-estimated every time the model is applied as opposed to many other assessments, where the reference points remain fixed until next benchmark, so it would make little sense to report these values.

The following reference points were used in the benchmark:

- Ffy/F_{MSY}: where F_{fy} is the estimated F in the final assessment year and F_{MSY} is the F that maximizes the equilibrium curve of yield versus F;
- Bfy/B_{MSY}: where B_{fy} is the estimated exploitable biomass in the final assessment year and B_{MSY} is the exploitable biomass corresponding to MSY in the equilibrium curve of yield versus stock biomass;
- $B_{fy}/B_{trigger}$: where $B_{trigger}$ is 0.5*B_{MSY};
- B_{fy}/B_{lim}: where B_{lim} is 0.3*B_{MSY}.

It is noted that B_{lim}=0.3*B_{MSY} is adopted based on the rationale that, under the Schaefer production (shape parameter n=2), the biomass corresponding to 50% of MSY is obtained at 30% of B_{MSY}. Although the stocks with approved SPiCT assessments in the benchmark are mainly characterized by a Schaefer production curve, WKMSYSPiCT considers that ICES should investigate and discuss the rationale to derive B_{lim} for other production models (e.g. Fox).

1.4 Catch forecast in SPiCT

SPiCT can run a short-term forecast for a set of management scenarios. Presently, there are eight pre-defined scenarios in SPiCT and additional functions for user-defined scenarios. These functions allow for different intermediate year assumptions and forecast options. Therefore, a wide range of harvest control rules can be defined and used. During WKMSYSPiCT, four different scenarios were selected as the most relevant options for the short-term catch forecast:

1. No fishing mortality (F = 0);
2. Status quo fishing mortality ($F = F_{sq}$);
3. Hockey-stick MSY rule: $F = F_{MSY}$ when biomass is higher than $B_{trigger}$ ($=0.5\ B_{MSY}$), but F is reduced linearly to zero when the biomass is less than $B_{trigger}$;
4. Hockey-stick MSY rule with the catch fractile: in order to take into account the estimated uncertainties, the 35th percentile of the catch distribution is used instead of the median (50th percentile). The fishing mortality assumption is the same as in 3.

The ICES MSY advice rule evaluates the biomass at the beginning of the management period as in the basis for advice on fishing opportunities (ICES, 2021).

For most stocks, the assessment is done using data for the prior year and do a short-term forecast to the end of the following year. This leaves a gap of data during the intermediate year. Due to lack of data in that period, some assumptions need to be made. Two plausible assumptions were discussed during WKMSYSPiCT and it was left for the assessors and the corresponding assessment groups to decide the most appropriate:

1. Status quo fishing mortality during the intermediate year;
2. A given catch is taken during the intermediate year. The catch could be, for example, the last agreed TAC for the stock.

An example SPiCT script implementing the above was provided to the participants during the benchmark meeting.

1.5 Recommendations

The following summary recommendations are made by WKMSYSPiCT, further elaborated below:

- SPiCT diagnostic should be extended to include runs test, retrospect forecasting and hindcasting;
- Historical catches should encompass earlier periods with relatively low exploitation and ideally the start of the fishery;
- When historical catches are not available the b/k ratio prior should be set to at 0.5 or lower with moderate to small CVs (i.e. 0.2–0.5). In these cases, it is generally recommended to evaluate the fits, retrospective pattern and ideally the prediction skill (see below) of additional sensitivity runs (e.g. b/k 0.3, 0.5, 0.8);
- For data that lack historical catches and show limited contrast in the abundance index, it is recommended to fix the n parameter and to use informative priors for r (e.g. Thorson, 2020);
- The standardization of commercial CPUE should include a spatial-time interaction factor, zeroes and different assumptions of technological creep;
- The generation of probability distributions in future version of SPiCT should also include for instance MCMC to check the Laplace approximation.

1.5.1 Diagnostics

SPiCT provides comprehensive model diagnostics to evaluate the fit to the data and retrospective analysis to evaluate model consistency. In particular, the functions to run and evaluate retrospective patterns have been substantially improved in the latest SPiCT version that was readily available for the benchmark assessment. Useful extensions for identifying model misspecification or data conflicts could be the implementation of a plot showing the process error deviates, to identify systemic patterns or regimes, and residual runs tests as an additional, easy to interpret and visualize check of randomness in the residuals of catch, indices and process error deviates (Carvalho *et al.*, 2017; Carvalho *et al.*, conditionally accepted). Considering that SPiCT is intended to be increasingly used for forecasting, it is recommended to extend the SPiCT diagnostic toolbox to enable retrospect forecasting of future states (Brooks and Legault, 2016; Carvalho *et al.*, conditionally accepted) and hindcast cross-validation to evaluate prediction skill (Kell *et al.*, 2016; Kell *et al.*, in conditionally accepted; Carvalho *et al.*, conditionally accepted), where prediction skill is a measure of the accuracy of an estimate compared to its observed value that is not known by the model. Hindcasting can be applied to any observed or empirical quantity for which the expected value can be forecasted, and has the additional advantage that it allows comparisons across model software. The relevant work cited herein has been uploaded to the SharePoint under "Background Documents" and implementation examples are available in the Github R libraries at github.com/JABBAmodel/ss3diags, github.com/JABBAmodel/JABBA and github.com/flr/a4adiags.

1.5.2 Historical catches

Several preliminary SPiCT runs that were presented during the data evaluation meeting considered relatively short catch time-series, although longer historical catch time-series were in several cases available. This appears to be consistent with common practice in ICES (Bouch *et al.*, 2020). However, when using surplus production models (SPMs), priority should be on reconstructing catch time-series that should encompass earlier periods with relatively low exploitation and ideally the start of the fishery. For stocks where catch time-series are much longer than CPUE time-series, it is generally recommended to add a prior on b/k, for example if catches in the start of the time-series are low compared to the rest, a prior close to b/k = 1 should be considered to improve model stability.

In cases where is not possible to reconstruct historical catches and catches are close the observed maximum at the start of the available time-series, the b/k ratio prior should be set to at 0.5 or lower with moderate to small CVs (i.e. 0.2–0.5) depending on the information content in the data. It is generally recommended to evaluate the fits, retrospective pattern and ideally the prediction skill (see above) of additional sensitivity runs (e.g. b/k 0.3, 0.5, 0.8).

1.5.3 Shape parameter and r

For data that lack historical catches and show limited contrast in the abundance index, it is recommended to reduce the variance for the shape parameter n or fix it. To further increase model stability, formulating informative priors for r (e.g. Thorson, 2020) may be warranted (see also github.com/henning-winker/SPMpriors). In general, the reviewers found it very helpful to see "control" Schaefer model scenarios with an informative r prior for comparison against a less constraint model. This is especially important when estimated r is very different from the r prior. It is important to note that r values from other models might not corresponds exactly to r values from SPiCT. Retrospective pattern is often related to uncertainty about the shape n parameter and fixing it or constraining it using prior, often reduce the retrospective pattern.

1.5.4 Standardisation of commercial CPUE

When commercial CPUE time-series are used in the stock assessment in general, specific consideration should be dedicated to the standardization procedure. In general, CPUE standardization analysis should be designed to account for spatial and targeting effects (fishing behaviour). Spatial effect may be dealt with using area and time interactions (random effect), GAMs (Gruss *et al.*, 2019) or geostatistical approaches, such as INLA or VAST (Thorson *et al.*, 2015). Spatio-temporal differences in abundance linked to environmental changes and/or depletion implies that the use of spatio-temporal models for standardizing fisheries-dependent CPUE data will be increasingly necessary in the future (Gruss *et al.*, 2019). Given that commercial fishing operations do not select their fishing grounds at random, but typically seek to maximize their catch and profits through adjusting their fishing tactics, it is important to consider targeting effects in the CPUE standardization model before the CPUE can be considered in the assessment, especially when the species under assessment is not the primary target species of the fishery. There are number of approaches that are based on the catch composition to derive covariates in the form of fishing tactic clusters (He *et al.*, 1997), principle components (Winker *et al.*, 2014), spatial dynamic factor analysis (Thorson *et al.*, 2016). We advise, however, against targeting factors that are based on catch proportions of the species under assessment because this is likely to result in removing abundance signal of interest (e.g. Hoyle *et al.*, 2014).

In general, the standardization procedure should include observations (e.g. hauls or trips) with zeroes, using appropriate error models, and vessels effect should be typically accounted for by way of random effects or through covariates for vessel characteristics. The year should also be modelled as a factor and not as a smoother when the commercial CPUE time-series is used in the assessment.

For sensitivity analysis, we also recommend to include different assumptions of technological creep (see Palomares and Pauly, 2019; Schrrer and Galbraith, 2020) and evaluate its effect on the stock status. Especially for long time-series of commercial CPUE, care should be given to consider the possible existence of technological creep and additional analysis to address this particular issue should be carried out.

1.5.5 Generation of probability distributions

The generation of probability distributions in future version of SPiCT should also include for instance MCMC to check the Laplace approximation.

1.6 References

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2 Tusk (*Brosme brosme*) in subareas 1 and 2 (usk.27.1–2)

2.1 Introduction

Tusk is a demersal fish of the family Gadidae. It is distributed from the eastern cost of Northern America, South Greenland, Iceland, Northern Ireland and north to the Barents Sea. For the most part tusk is caught in longline fishery, but also in gillnet, trawl and trap fishery. The commercial value of the fishery is relatively high, and the catch is landed for human consumption. Recruitment to the fished stock starts at about 30 cm (4–5 years old), and peaks at about 50 cm (ten years old).

Tusk prefers hard, or sandy sea-beds with large rocks. It inhabits depths ranging from 50–1000 m but is mainly found between 200 and 500 m (Pethon, 2019). It is believed that tusk occur alone or in small schools (Gordon *et al*., 1995). The maximum weight and length of tusk is about 15 kg and 1.1 m, respectively. Tusk matures between six and eight years old. The growth is slow (k=0.15) and they can be up to 40 years old. Natural mortality is usually set to 0.2. Tusk feed mainly on shrimps, crabs and small fish (Magnusson *et al*., 1997; Pethon, 2019).

Figure 2.1.1 shows the spatial distribution of tusk and the total catch by the Norwegian longline fishery in 2019. The distribution of the fishery changes very little from year to year. More information about the distribution of catches for the Norwegian longline fishery during the period 2013 to 2019 is shown in ICES (2020).

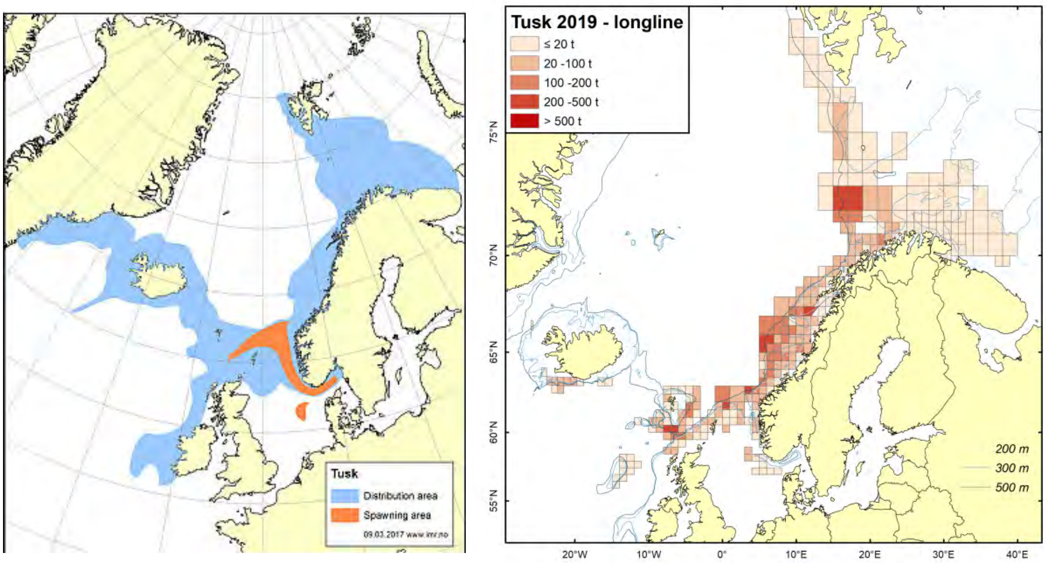

Figure 2.1.1. Distribution of tusk and distribution of catches for the Norwegian longline fishery in subareas 1 and 2 in 2019.

In subareas 1 and 2 tusk is primarily a bycatch species in fisheries targeting, for example, ling, cod or haddock. Currently the major fisheries in subareas 1 and 2 are the Norwegian longline and gillnet fisheries, but there are also bycatches by other gears, e.g. trawls and handlines. The total Norwegian landings are usually around 85% from longlines, 10% from gillnets and the remainder by other gears. For other nations, tusk is bycatch in trawl and longline fisheries. Figure 2.1.2 show the proportion of tusk divided between bycatch and targeted Norwegian longline fishery. It appears that the proportion of tusk as bycatch has increased since 2000.

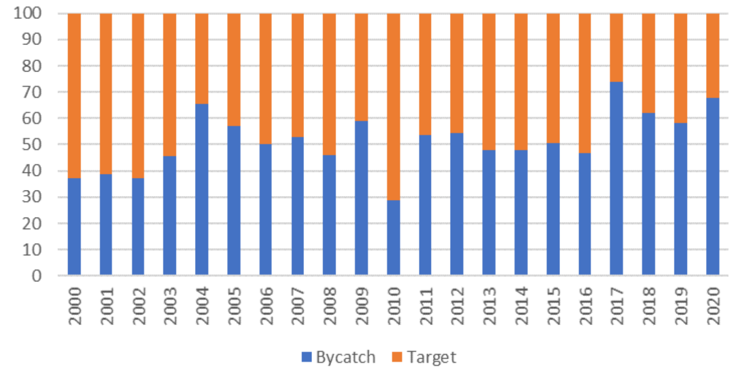

Figure 2.1.2. Proportion of catches of tusk divided between bycatch and targeted fishery.

Management of tusk in subareas 1 and 2 is based on the precautionary approach. The ICES advice is that catches should be no more than 11 077 t in 2020 and in 2021. Total catches are assumed to be landed.

There is no quota for the Norwegian tusk fishery, but vessels participating in the directed fishery for ling or tusk in subareas 1 and 2 are required to have a licence. There is no minimum landing length in the Norwegian EEZ.

The EU TAC (for community vessels fishing in community waters and waters not under the sovereignty or jurisdiction of third countries in 1, 2 and 14) was set to 21 t in 2019.

2.2 Input data for stock assessment (ToR 1 & 2)

2.2.1 Landings data

Landings were downloaded from the ICES database for the period 1908 to 2019. For 2020, preliminary landings were downloaded from the Norwegian Directorate Fisheries and preliminary landings were estimated based on these.

The landings statistics for tusk should ideally reflect the state of the stock, but to a very large extent, the amount landed reflects the size of the fleet and variable fishery regulations. The early data before World War II are doubtful; however, after the war the landings statistics are more reliable. Immediately after the war, the fleet consisted of small, wooden boats with limited range and little storage capacity. During the 1960s, the fleet gradually shifted to larger steel boats that had greater range and capacity. In 1977, automatic baiting machines were introduced and by the end of the 1980s, about 95 percent of the boats had converted to autolines. The Norwegian longline fleet (vessels larger than 21 m) increased from 36 in 1977 to a peak of 72 in 2000. Due to this increase in number of vessels the fishing pressure became so great that regulations were implemented that in effect reduced the longline fleet from 72 boats in 2000 to 35 boats in 2010 and after new regulations implemented in 2012 the number of vessels were reduced to 26.

The history of the fishery shows several regime shifts from 1908 to 2020 (Figure 2.2.1). These shifts should be taken into consideration when catches are used in any analysis. Especially for a bycatch species such as tusk, the landings very likely show the fishing activity rather than reflecting the status of the stock.

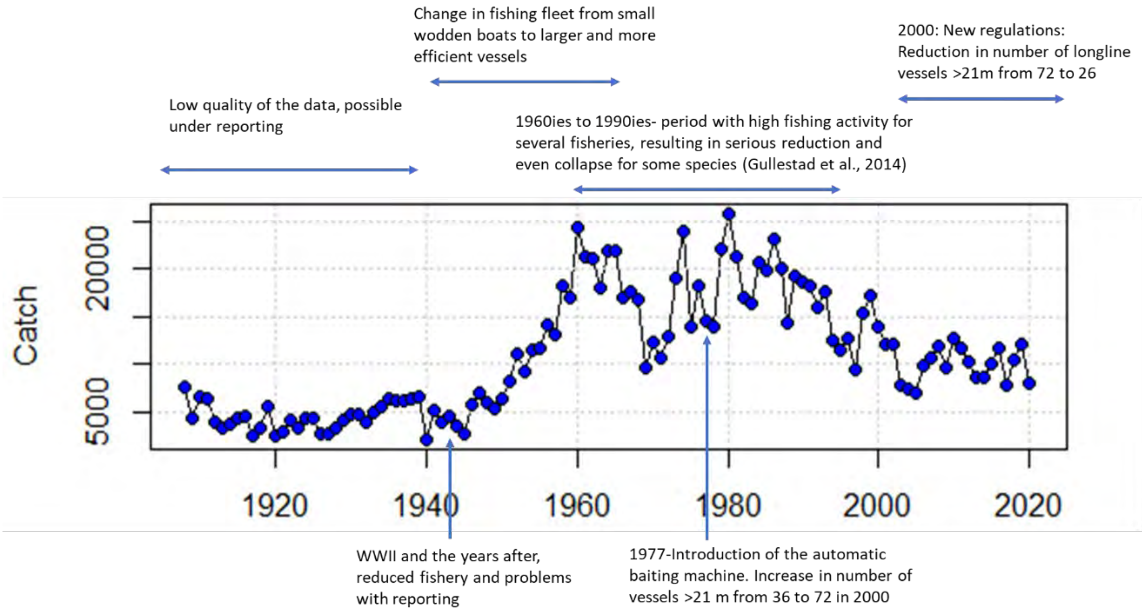

Figure 2.2.1. Catches from 1908 to 2020 including the changes in landing regimes during this period.

2.2.2 CPUE based on longline data

Norway began in 2003 to collect and enter data from official logbooks into an electronic database, and these data are now available for the period 2000–2020. Vessels were selected that had a total landed catch of ling, tusk and blue ling exceeding 8 t each year. The logbooks contain records of the daily catch, date, position, and number of hooks used per day.

A number of methods to estimate a CPUE index have been tested, and the most applicable method was found to be a GLM model; using year, month, and ship as categorical factors and the method is described in Helle *et al.* (2015).

0-values were also included in some of the analysis. Finding the correct 0-values was very time consuming, and the results for the CPUE including the 0-values and using all data available were so small and followed the same trend. Hence it was decided not including the 0-values in the further work.

For the assessment done in WGDEEP, two different CPUE indices have been estimated for the stock; one with all data available (allData) and one with data from the vessels that more than 30% of the catch was tusk (targeted). The results for the two indices are shown in Figure 2.2.2.

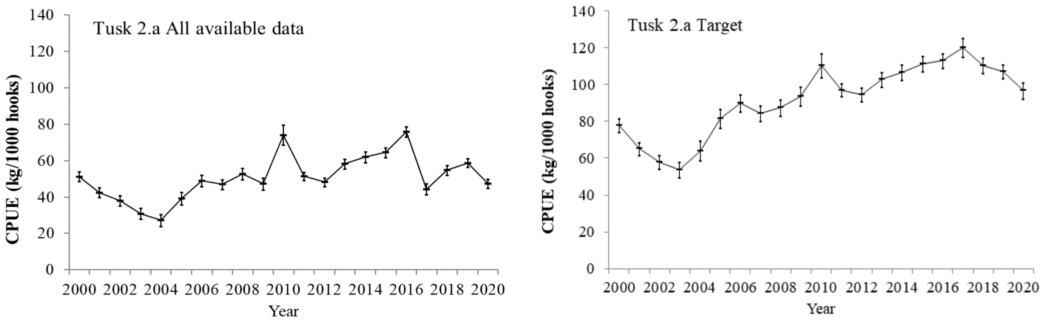

Figure 2.2.2. Estimates of cpue (kg/1000 hooks) of tusk based on skipper's logbook data for 2000–2020. The bars denote the 95% confidence interval.

While collecting data for the CPUE index technical data from the Norwegian longline fleet was collected using information from the manufacturers of baiting machines and fishing hooks. The data including type of baiting machines, when they were changed, hook types and hook size and what vessels that have moonpool (Hareide and Helle, 2012 working document). We also interviewed several vessel owners/ skippers to categorize other changes in the fishery. The data were analyzed to detect technological creep, but we did not get any consistent patterns in the data. The main change since 2000 has been the introduction of the baiting machine "Super baiter", which can bait and set more hooks than the previous machines. There is a linear correlation between the catch and the number of hooks set (Helle *et al.*, 2015) which did not affect the CPUE. Major changes, such as the shape of the hooks and development of snoods, happened before 2000.

2.3 Stock assessment (ToR 3)

It was not possible for the group to recommend or approve a SPiCT assessment for this stock. The reason for this was primarily the construction of the CPUE index; the CPUE index itself was not disregarded but it was not regarded suitable for the SPiCT model. Two points were pointed out as problematic; the targeting effect and technological creep. Especially handling the targeting effect; the spatial-time interactions must be solved before data can be used by SPiCT.

Following the above arguments on targeting effects the allData CPUE would emolliate the effects from targeting but neither of the two CPUE indices were regarded appropriate.

In general, there were problems having the model to converge for this stock. The last years of the catch series was almost stable, while there was a large increase in the CPUE index in the same period which made the model to depend on the information from the index.

The trend in targeted CPUE index was regarded as unrealistic according to the steepness of the increase seen on a short period of time (14 years). The increase in targeted CPUE was two times higher than the one for the allData CPUE.

2.3.1 Exploratory assessments

The exploratory assessment shows the different trials we did before and at the benchmark meeting on the catch series and the two CPUE indices for this stock.

The recommendations from the data work group meeting was to run the assessments with long time-series on catches, run trials with both the targeted and allData CPUE series and to apply priors on n and B/K.

Two different CPUE indices were tried for the stock; one with all data available (allData) and one with data from the vessels that more than 30% of the catch was tusk (targeted), method is described in Helle *et al*. (2015). For landings data long series from 1908 were used, a medium series from 1970 and short series from 1988. The three different catch series were used together with the two CPUE series: all with several different settings for priors.

The process of work and fits to the model are described in Table 2.3.1.

When running the model with short time-series and both default settings and prior on n=2 and B/K=0.9 convergence was succeeded with the targeted CPUE.

When extending the landing series back to 1908 no convergence was succeeded with default values for neither CPUE indices.

Different priors were tried to make the model converge. Primarily, the prior on n and B/K were used but also priors on logsdf, logsdc and logsdi were tried. Prior on logn was used when the production curve was skewed to left/right and prior on initial depletion level was used to inform the status of exploitation level in the beginning of the catch series. Since the catch time-series was much longer than the CPUE time-series, prior on b/k ≈ 1 was applied to reflect that both the catches and the fishery was at low levels in the beginning of the time-series. There were always difficulties getting the model to converge. Concerning the quality of data, the year 2010 was deleted from the CPUE series because this datapoint was not representative for the CPUE this year. There were still difficulties getting the model to converge.

None of the runs from both the targeted and allData CPUE would converge with good results (Table 2.3.1).

2.3.1.1 Usk_arct_targeted

Input data for tusk targeted are shown in Figure 2.3.1a-c. Since data from 2010 were regarded to be not representative for the CPUE that year, it was tried to run the model without this year, too. Fitting the model with long catch series and defaults values did not converge (Table 2.3.1). Then tried to apply different priors according to Table 2.3.1. Scenario 8 converged (Figure 2.3.2a), but the estimates for B_{MSY}, F_{MSY} and MSY gave no meaningful values (Table 2.3.3); the diagnostic plots showed problems with autocorrelation (Figure 2.3.2b) and the retrospective plots could not be produced.

Since the year 2010 could have caused problems for the diagnostics, this year was deleted and new fits to the model were tried (Table 2.3.1). Scenario 10 gave convergence (Figure 2.3.3a); the diagnostics showed problems with normality now (Figure 2.3.3b). The retrospective plots could not be produced.

Using scenario 14, the catch series from 1970 with B/K=0.2, the model converged possibly because of the higher catches in 1950–1970 making the argument for using the lower initial depletion level. Result plots, diagnostics and retrospective plots are shown in Figures 2.3.4a–c.

2.3.1.2 Usk_arct_alldata

None of the runs for tusk allData with long catch series would converge except scenario 28 (Table 2.3.1). This scenario was presented to the meeting and the input data are shown in Figure 2.3.5a. The result plots, diagnostics and retrospective plots are shown in Figures 2.3.5b–d and parameter estimates in Table 2.3.5.

2.3.1.3 Comments on the assessment

The catch series is almost stable at the end of the series; this causes troubles with the contrast in the data as the targeted CPUE has a very steep increase in the same period. The increase in allData CPUE is not as pronounced as the targeted CPUE and that is probably why the model fits better to this scenario. Because of the lack of contrast, the CPUE index will be driving the model.

The very steep increase in CPUE over the short time period is problematic as the model estimate the stock to be 2–4 times B_{MSY} and to have F below F_{MSY}. The very high r (0,3–1,0) (Table 2.3.2) seems to be unrealistic as the expected value for r should be 0.12 for tusk (SPMpriors from FishLife).

Stock status assessed by SPiCT indicated that B was above B_{MSY} and F below F_{MSY}. Other models were tried (see reviewers report) that came to contradictory conclusions. The development on B and F from SPiCT were to the assessors not totally unrealistic as the result plots to some extent resembled the history of the fishery and the believed present stock status for tusk in this area. The problem is that F probably was higher in the 1970–1980s than the model estimate. Together with the increase in CPUE this probably makes the results from the SPiCT model to be too optimistic.

The assessments on SPiCT could not be approved according to the uncertainty in the CPUE index and due to the observed inconsistencies described above.

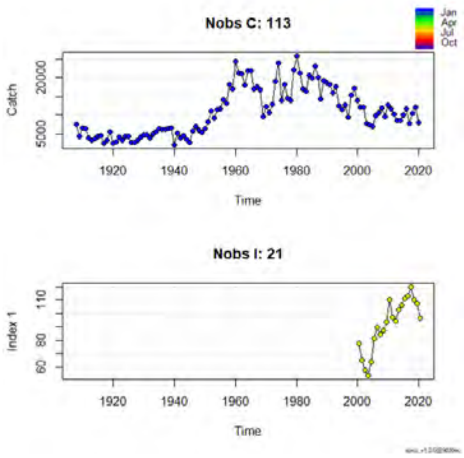

Figure 2.3.1a. Input data for usk_arct_targeted.

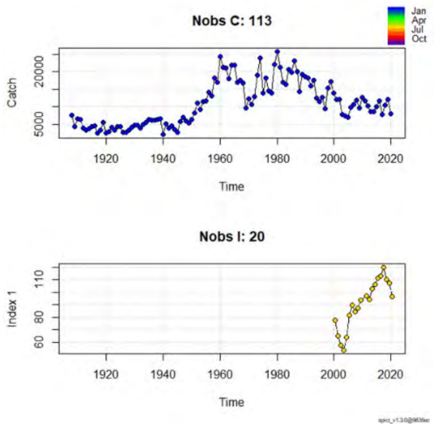

Figure 2.3.1b. Input data for usk_arct_targeted with deleted year 2010.

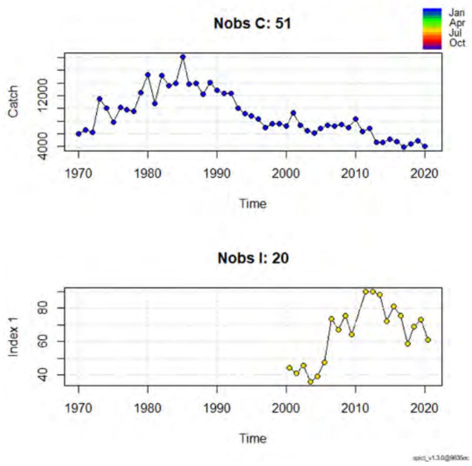

Figure 2.3.1c. Input data for usk_arct_targeted from 1970–2020 and deleted year 2010.

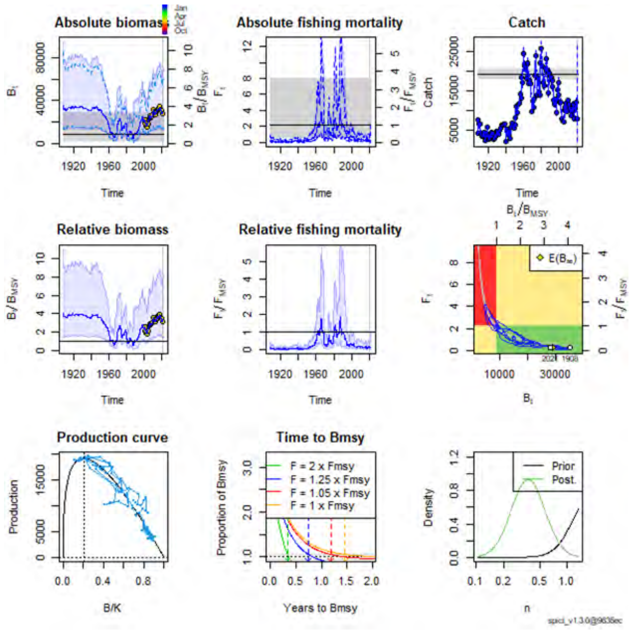

Figure 2.3.2a. Result plots for usk_arct_targeted from scenario 8.

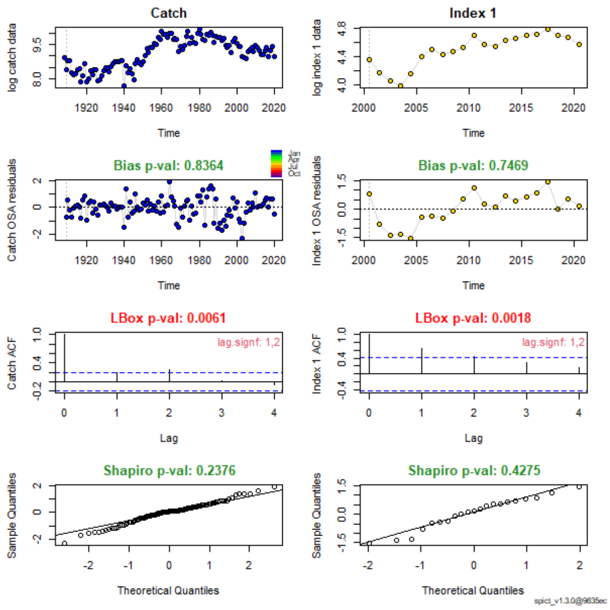

Figure 2.3.2b. Diagnostics for usk_arct_targeted from scenario 8.

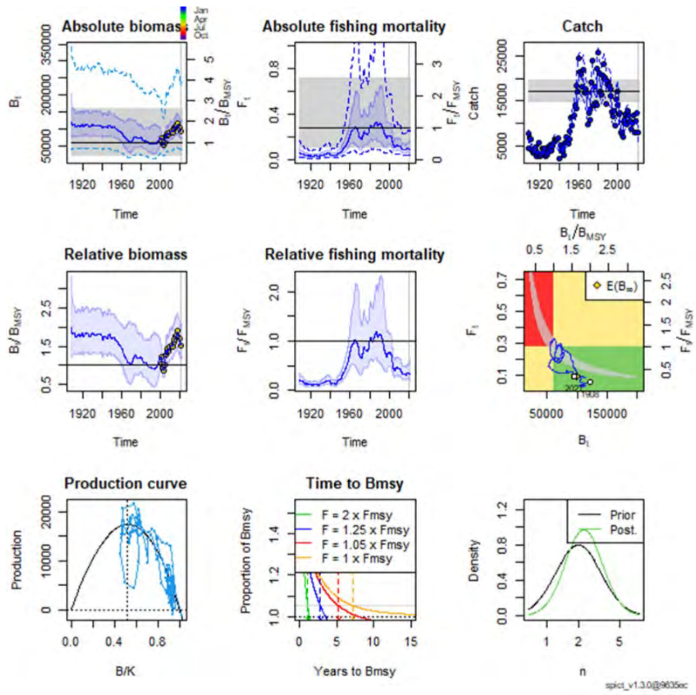

Figure 2.3.3a. Result plots on usk_arct_targetd from scenario 10.

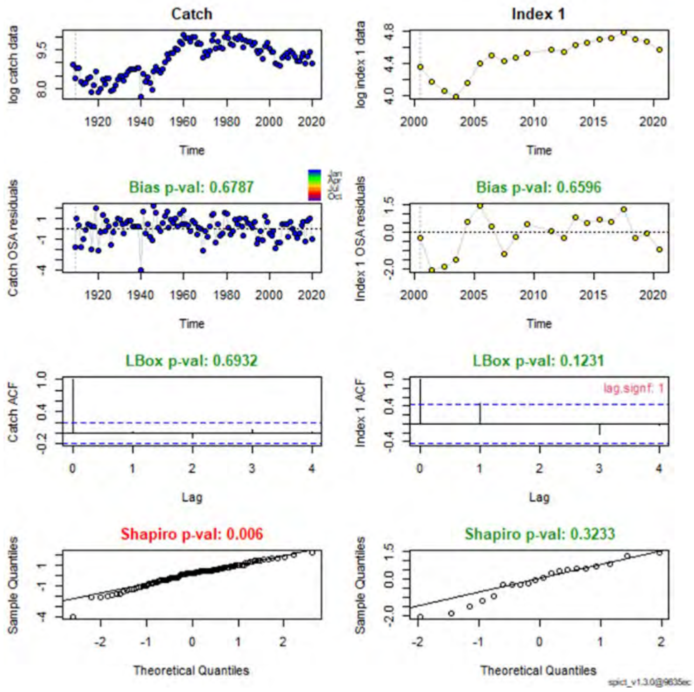

Figure 2.3.3b. Diagnostics on usk_arct_targeted from scenario 10.

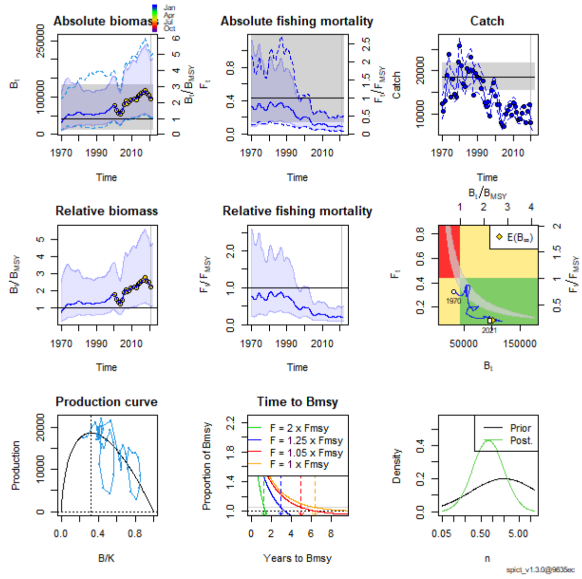

Figure 2.3.4a. Result plot from scenario 14.

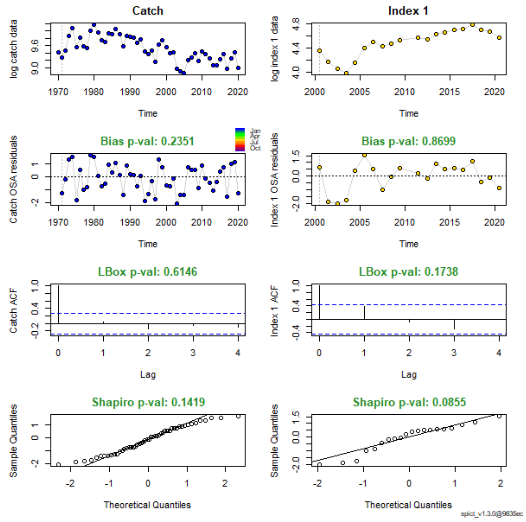

Figure 2.3.4b. Diagnostics for the scenario 14.

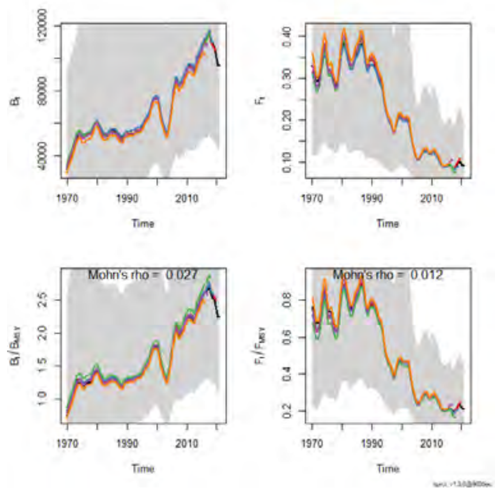

Figure 2.3.4c. Retrospective plots for scenario 14.

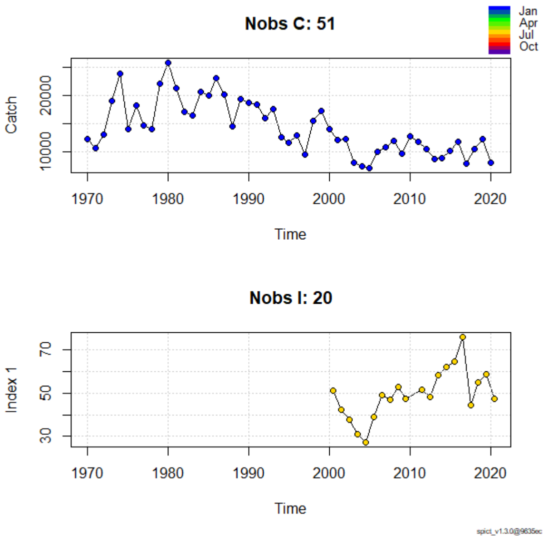

Figure 2.3.5a. Input data for scenario 28.

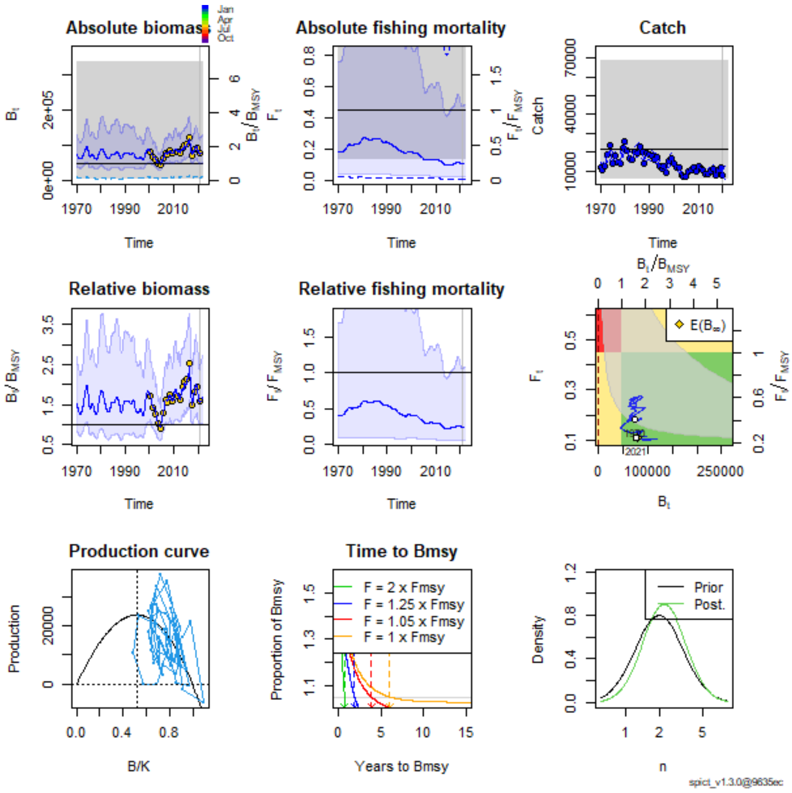

Figure 2.3.5b. Result plots for scenario 28.

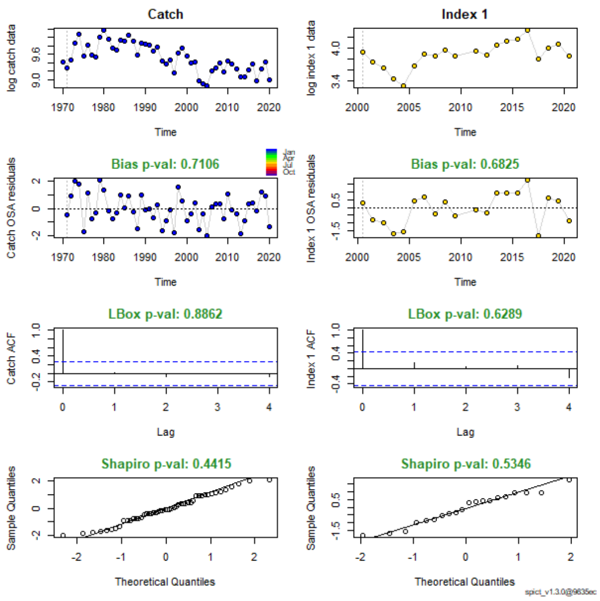

Figure 2.3.5c. Diagnostics for scenario 28.

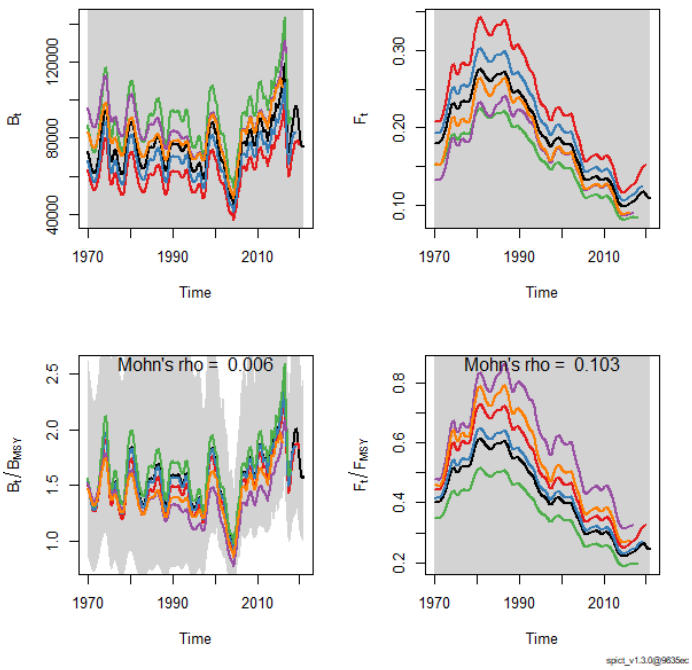

Figure 2.3.5d. Retrospective plots for scenario 28.

Table 2.3.1. Scenarios for working process and fits on tusk arct area. Runs from both the data workgroup meeting and benchmark meeting.

	Scenarios	Landings	CPUE	Priors	Results
Tusk_arct_targeted	1	1988–2020	2000–2020	Defaults	Convergence, left skewed production curve
	2	1988–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1)	Convergence, left skewed production curve
	3	1988–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, production curve ok, diagnostics and retrospective ok
	4	1908–2020	2000–2020	Defaults	No convergence
	5	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1)	No convergence
	6	1908–2020	2000–2020	Inp$prior$logn<-c(log(1.5),0.6,1)	No convergence
	7	1908–2020	2000–2020	Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	No convergence
	8	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	Convergence, but no reasonable values for Bmsy, Fmsy and MSY. Diagnostics not ok and could not produce retroplots
	9	1908–2020	2000–2020	Uncertainty on stdevfacC=5 (2000–2020) Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	No convergence

	Scenarios	Landings	CPUE	Priors	Results
	10	1908–2020	2000-2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, diagnostics not ok, could not produce retro plots
	11	1908–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1)	No convergence
	12	1908–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	No convergence
	13	1970-2020	2000-2020 (-2010)	Defaults	Convergence, diagnostocs ok, retro not so ok
	14	1970–2020	2000–2020 (–2010)	#high exploitation before the beginning of the available data: inp$priors$logbkfrac <-c(log(0.2),0.5,1)	Convergence, production curve slightly to the right, diagnostics and retrospective ok
	15	1970–2020	2000–2020 (–2010)	#low or no exploitation before the beginning of the available data inp$priors$logbkfrac <-c(log(0.8),0.5,1)	No convergence
Tusk_arct_allData	16	1988–2020	2000–2020	Defaults	Convergence, production curve, diagnostics and retrospective not ok
	17	1908–2020	2000–2020	Defaults	No convergence
	18	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1)	No convergence
	19	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	No convergence

Scenarios	Landings	CPUE	Priors	Results
20	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1)	No convergence
21	1908–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	No convergence
22	1908–2020		Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Inp$priors$logsdi<-log(0.1),0.2,1) Disable logalpha and logbeta	No convergence
23	1908–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	No convergence
24	1908–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	No convergence
25	1908–2020	2000–2020 (–2010)	stdevfacC=5 (2000-2020) Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1) Inp$priors$logsdf<-log(2),0.1,1) Inp$priors$logsdc<-log(0.1),0.1,1) Disable logalpha and logbeta	No convergence
26	1970–2020	2000–2020 (–2010)	Defaults	No convergence

Scenarios	Landings	CPUE	Priors	Results
27	1970–2020	2000–2020 (–2010)	#high exploitation before the beginning of the available data: inp$priors$logbkfrac <- c(log(0.2),0.5,1)	No convergence
28	1970–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) inp$priors$logbkfrac <- c(log(0.9),0.25,1)	Convergence, Diagnostics ok, retro not ok

Table 2.3.2. Results from SPiCT runs on tusk arct targeted and allData.

	Targeted			**AllData**
	Scenario 8	Scenario 10	Scenario 14	Scenario 28
B_{MSY}	8488	61190	42734	48151
F_{MSY}	2.23	0.28	0.43	0.45
MSY	19080	17001	18512	21560
B/B_{MSY}	3.15	1.54	2.25	1.58
F/F_{MSY}	0.12	0.34	0.21	0.24
R	0.93	0.63	0.34	1.03
K	37028	118403	133182	98059

Table 2.3.3. Results from Scenario 10; output from the model.

```
Convergence: 0  MSG: both X-convergence and relative convergence (5)
Objective function at optimum: 1.2903453
Euler time step (years):  1/16 or 0.0625
Nobs C: 113,  Nobs I1: 20

Priors
     logn  ~  dnorm[log(2), 0.5^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]
 logbkfrac  ~  dnorm[log(0.9), 0.25^2]

Model parameter estimates w 95% CI
          estimate       cilow        ciupp    log.est
 alpha  1.736366e-01 2.475690e-02 1.217831e+00 -1.7507906
 beta   1.067947e+00 6.566547e-01 1.736851e+00  0.0657382
 r      6.344151e-01 2.231594e-01 1.803565e+00 -0.4550518
 rc     5.621297e-01 2.198815e-01 1.437091e+00 -0.5760227
 rold   5.046318e-01 1.402332e-01 1.815928e+00 -0.6839262
 m      1.741534e+04 1.504500e+04 2.015912e+04  9.7651066
 K      1.184030e+05 4.703158e+04 2.980819e+05 11.6818492
 q      1.036500e-03 4.222000e-04 2.544400e-03 -6.8719289
 n      2.257184e+00 1.008840e+00 5.050236e+00  0.8141180
 sdb    9.994440e-02 6.508330e-02 1.534784e-01 -2.3031416
 sdf    1.664608e-01 1.156562e-01 2.395824e-01 -1.7929957
 sdi    1.735400e-02 2.652000e-03 1.135594e-01 -4.0539322
 sdc    1.777713e-01 1.441743e-01 2.191974e-01 -1.7272575

Deterministic reference points (Drp)
         estimate       cilow        ciupp   log.est
 Bmsyd 6.196200e+04 2.358065e+04 1.628152e+05 11.034277
 Fmsyd 2.810648e-01 1.099408e-01 7.185456e-01 -1.269170
 MSYd  1.741534e+04 1.504500e+04 2.015912e+04  9.765107
Stochastic reference points (Srp)
         estimate       cilow        ciupp   log.est
 Bmsys 6.118978e+04 2.335381e+04 1.603246e+05 11.021736
 Fmsys 2.780093e-01 1.075992e-01 7.183063e-01 -1.280101
 MSYs  1.700897e+04 1.475809e+04 1.960315e+04  9.741496
      rel.diff.Drp
 Bmsys  -0.01261994
 Fmsys  -0.01099081
 MSYs   -0.02389139
```

```
States w 95% CI (inp$msytype: s)
                 estimate       cilow       ciupp
B_2020.94      9.436512e+04 3.822735e+04 2.329425e+05
F_2020.94      9.348100e-02 3.584060e-02 2.438213e-01
B_2020.94/Bmsy 1.542171e+00 1.190759e+00 1.997291e+00
F_2020.94/Fmsy 3.362514e-01 2.094969e-01 5.396977e-01
                log.est
B_2020.94      11.4549268
F_2020.94      -2.3699969
B_2020.94/Bmsy  0.4331913
F_2020.94/Fmsy -1.0898962

Predictions w 95% CI (inp$msytype: s)
               prediction       cilow       ciupp
B_2022.00      9.651486e+04 3.890305e+04 2.394444e+05
F_2022.00      9.348120e-02 3.384560e-02 2.581944e-01
B_2022.00/Bmsy 1.577303e+00 1.192359e+00 2.086525e+00
F_2022.00/Fmsy 3.362520e-01 1.881743e-01 6.008546e-01
Catch_2021.00  8.930654e+03 6.007440e+03 1.327630e+04
E(B_inf)       9.817896e+04           NA           NA
                log.est
B_2022.00      11.4774523
F_2022.00      -2.3699950
B_2022.00/Bmsy  0.4557168
F_2022.00/Fmsy -1.0898944
Catch_2021.00   9.0972449
E(B_inf)       11.4945472
```

Table 2.3.4. Results from scenario 14; output from the model.

Convergence: 0 MSG: relative convergence (4)

Objective function at optimum: -12.3122695

Euler time step (years): 1/16 or 0.0625

Nobs C: 51, Nobs I1: 20

Priors

logn ~ dnorm[log(2), 2^2]

logalpha ~ dnorm[log(1), 2^2]

logbeta ~ dnorm[log(1), 2^2]

logbkfrac ~ dnorm[log(0.2), 0.5^2]

Model parameter estimates w 95% CI

	estimate	cilow	ciupp	log.est
alpha	1.972638e-01	2.714040e-02	1.433767e+00	-1.6232133
beta	8.522115e-01	3.532277e-01	2.056080e+00	-0.1599205
r	3.372134e-01	1.020056e-01	1.114770e+00	-1.0870394
rc	8.653389e-01	2.924083e-01	2.560842e+00	-0.1446340
rold	1.528471e+00	9.222000e-04	2.533256e+03	0.4242682
m	1.861811e+04	1.580927e+04	2.192599e+04	9.8318898
K	1.331820e+05	6.167548e+04	2.875934e+05	11.7994723
q	1.013600e-03	4.642000e-04	2.213100e-03	-6.8942605
n	7.793787e-01	1.271690e-01	4.776566e+00	-0.2492582
sdb	9.957480e-02	6.877830e-02	1.441611e-01	-2.3068458
sdf	1.619539e-01	8.819880e-02	2.973857e-01	-1.8204436
sdi	1.964250e-02	2.893700e-03	1.333352e-01	-3.9300591
sdc	1.380190e-01	9.386230e-02	2.029488e-01	-1.9803641

Deterministic reference points (Drp)

	estimate	cilow	ciupp	log.est
Bmsyd	4.303078e+04	1.371377e+04	1.350211e+05	10.6696710
Fmsyd	4.326695e-01	1.462041e-01	1.280421e+00	-0.8377812
MSYd	1.861811e+04	1.580927e+04	2.192599e+04	9.8318898

Stochastic reference points (Srp)

	estimate	cilow	ciupp	log.est
Bmsys	4.273536e+04	1.372997e+04	1.330164e+05	10.6627820
Fmsys	4.331747e-01	1.457544e-01	1.287373e+00	-0.8366143
MSYs	1.851202e+04	1.574641e+04	2.176337e+04	9.8261758

	rel.diff.Drp
Bmsys	-0.006912807
Fmsys	0.001166367
MSYs	-0.005730367

```
States w 95% CI (inp$msytype: s)
                  estimate       cilow       ciupp
 B_2020.94      9.595083e+04 4.370138e+04 2.106698e+05
 F_2020.94      8.976510e-02 3.915090e-02 2.058134e-01
 B_2020.94/Bmsy 2.245233e+00 1.087727e+00 4.634500e+00
 F_2020.94/Fmsy 2.072261e-01 9.203410e-02 4.665952e-01
                  log.est
 B_2020.94      11.4715911
 F_2020.94      -2.4105590
 B_2020.94/Bmsy  0.8088091
 F_2020.94/Fmsy -1.5739447

Predictions w 95% CI (inp$msytype: s)
                prediction       cilow       ciupp
 B_2022.00      9.766946e+04 4.428611e+04 2.154022e+05
 F_2022.00      8.976530e-02 3.679070e-02 2.190175e-01
 B_2022.00/Bmsy 2.285448e+00 1.094197e+00 4.773613e+00
 F_2022.00/Fmsy 2.072265e-01 8.637440e-02 4.971708e-01
 Catch_2021.00  8.695220e+03 6.012435e+03 1.257508e+04
 E(B_inf)       1.017447e+05          NA          NA
                  log.est
 B_2022.00      11.4893442
 F_2022.00      -2.4105570
 B_2022.00/Bmsy  0.8265622
 F_2022.00/Fmsy -1.5739427
 Catch_2021.00   9.0705287
 E(B_inf)       11.5302223
```

Table 2.3.5. Result table of Scenario 28; output from the model.

```
Convergence: 0  MSG: both X-convergence and relative convergence (5)
Objective function at optimum: -5.7001621
Euler time step (years):  1/16 or 0.0625
Nobs C: 51,  Nobs I1: 20

Priors
     logn  ~  dnorm[log(2), 0.5^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]
 logbkfrac  ~  dnorm[log(0.9), 0.25^2]

Model parameter estimates w 95% CI
         estimate       cilow       ciupp    log.est
 alpha  1.633386e-01 2.532890e-02 1.053323e+00 -1.8119300
 beta   9.330566e-01 2.814711e-01 3.093016e+00 -0.0692894
 r      1.031244e+00 3.385265e-01 3.141451e+00  0.0307658
 rc     9.295564e-01 3.126381e-01 2.763819e+00 -0.0730478
 rold   8.461230e-01 1.877347e-01 3.813488e+00 -0.1670905
 m      2.370004e+04 7.283674e+03 7.711658e+04 10.0732322
 K      9.805891e+04 1.418923e+04 6.776655e+05 11.4933237
 q      6.215000e-04 7.220000e-05 5.349500e-03 -7.3834110
 n      2.218787e+00 9.321256e-01 5.281495e+00  0.7969608
 sdb    2.410092e-01 1.526216e-01 3.805847e-01 -1.4229202
 sdf    1.080464e-01 4.544840e-02 2.568630e-01 -2.2251949
 sdi    3.936610e-02 6.733900e-03 2.301329e-01 -3.2348502
 sdc    1.008134e-01 5.738400e-02 1.771110e-01 -2.2944843

Deterministic reference points (Drp)
        estimate      cilow       ciupp   log.est
 Bmsyd 5.099216e+04 7252.548613 358522.27314 10.839427
 Fmsyd 4.647782e-01    0.156319      1.38191 -0.766195
 MSYd  2.370004e+04 7283.674473  77116.58353 10.073232
Stochastic reference points (Srp)
        estimate       cilow       ciupp    log.est
 Bmsys 4.815083e+04 6880.8896064 3.369481e+05 10.7820937
 Fmsys 4.487019e-01    0.1431895 1.406062e+00 -0.8013966
 MSYs  2.155969e+04 6772.5862769 6.863262e+04  9.9785808
      rel.diff.Drp
 Bmsys  -0.05900882
 Fmsys  -0.03582849
 MSYs   -0.09927562
```

```
States w 95% CI (inp$msytype: s)
                  estimate      cilow       ciupp
B_2020.94      7.589709e+04 8971.9464018 6.420422e+05
F_2020.94      1.095811e-01    0.0130135 9.227340e-01
B_2020.94/Bmsy 1.576236e+00    1.0031723 2.476664e+00
F_2020.94/Fmsy 2.442181e-01    0.0560101 1.064852e+00
                  log.est
B_2020.94      11.2371336
F_2020.94      -2.2110900
B_2020.94/Bmsy  0.4550399
F_2020.94/Fmsy -1.4096934

Predictions w 95% CI (inp$msytype: s)
                 prediction      cilow       ciupp
B_2022.00      8.098480e+04 9982.9033855 6.569771e+05
F_2022.00      1.095813e-01    0.0128693 9.330811e-01
B_2022.00/Bmsy 1.681898e+00    1.0413134 2.716552e+00
F_2022.00/Fmsy 2.442185e-01    0.0551163 1.082124e+00
Catch_2021.00  8.634206e+03 5982.6447597 1.246096e+04
E(B_inf)       8.061512e+04           NA          NA
                  log.est
B_2022.00      11.3020168
F_2022.00      -2.2110884
B_2022.00/Bmsy  0.5199231
F_2022.00/Fmsy -1.4096918
Catch_2021.00   9.0634870
E(B_inf)       11.2974416
```

2.4 Future considerations/recommendations

If using SPiCT for future assessment, the CPUE index must be constructed to better incorporate the effects of targeting, zero-catches and technological creep.

Since there are data available on length compositions the use of other integrated models should be considered. However, input data should be quality controlled as the life history parameters are highly uncertain.

It is recommended that the assessment for tusk in this area is using the 3.2 rule advice until there is an assessment using SPiCT or other integrated models available.

2.5 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

The assessments of tusk Tusk in subareas 1 and 2 (usk_arct) and Tusk in divisions 3a, 4a, 5b, 6a and subareas 7–9 and 12 (usk_other) are both based on a standardized CPUE time-series of the commercial longline fishery and official catch data. The standardized CPUE is short, starting in 2000 while catches of both stocks were reported to ICES already in 1920, but commercial fisheries for tusk in the North Sea with longlines is already known to exist since 1860 or possibly even before (Cardinale *et al*., 2014).

For both stocks, the standardisation procedure of the commercial CPUE of the longliners catching tusk followed the methods outlined in Helle *et al*. (2015), which involved using (i) all data and (ii) only using a subset of data from vessels regularly targeted tusk in a given year (i.e. where more than 30% of the catch were tusk). The standardization model only considered the fixed year, month and vessel. However, important factors, such as area, area-year interactions and targeting factors (see e.g. Winker *et al*., 2014; Hoyle *et al*., 2014; Thorson *et al*., 2016) were not accounted for. In particular, the large stock areas would require careful consideration of impacts of spatio-temporal variation in CPUE (see e.g. Gruss *et al*., 2019). It was also noted that according to Helle *et al*. (2015) the probability of encounter a positive observation for the all data was not standardized. To overcome this, GLMMs or GAMMs with Tweedie distributions could be explored in future. This would allow including zeros, treat vessels and area-space interactions as random effects and/or catch locations as non-linear predictor variables.

The base case SPiCT model uses recent landings (i.e. since 1988) and the CPUE of the vessels targeting tusk for both stocks, however, the CPUE standardization does not account for targeting effect, nor for technological creeping which makes it not suitable to be used in stock assessment models. The CPUE of all vessels catching tusk at least emolliated the targeting effect. This is particularly important as the two indices show a rather different trend, with the CPUE including all vessels being flat or slightly increasing while the CPUE of the vessels targeting tusk increasing over time for both stocks. The effect of targeting was greatest for the arctic tusk stock, since the CPUE indices including all vessels showed a much different trend compared to only targeting vessels, whereas for the North Sea stock this difference was less pronounced.

The stock assessors investigated the effect of the inclusion of the historical landing data in the model for both stocks as suggested during the data meeting of WKMSYSPiCT. The different model configurations do not appear to be much influenced by the historical catch data but mostly by the CPUE trend in the recent years, by the assumption on effort creep, by the inclusion of the historical CPUE (derived from ICES, 2010) and by the priors. All SPiCT models tested and presented estimated the stock to be between two and four times B_{MSY} and current F to be well below F_{MSY} in the last year for the Arctic tusk stock.

Two alternative models were run, a JABBA surplus production model based on catches and commercial CPUE (thus similar to SPiCT but with the addition of the historical CPUE and assumptions of technological creep) and a length-based Stock Synthesis model (SS; the latter was run only for Arctic tusk for illustration) that includes also the size compositions of the catches and life-history parameters as growth, mortality and maturity and explicitly model the selectivity of the fleet but does not include historical CPUE and assumes no technological creep for the modern CPUE. The JABBA models were run for both stocks with historical CPUE (to improve stability) and modern CPUE and no technological creep and with 2% annual creep for both CPUE time-series, which is considered as a minimum estimate (Palomares and Pauly, 2019; Scherrer and Galbraith, 2020).

The results of those alternative models are very different from the base case SPiCT model as the stock is estimated to range of being close to B_{MSY} and F_{MSY} to be overfished and in overfishing, with the SSB less than any plausible candidate of B_{lim} (Figures 2.5.1–2.5.4). This pattern is however less pronounced for North Sea tusk compare to Arctic tusk. Most importantly, while results of the Stock Synthesis models are always consistent with a depleted stock (Figure 2.5.5), JABBA results are heavily influenced by inclusion of historical CPUE and technological creep, with the results ranging from a stock around B_{MSY} and F_{MSY} (and thus more similar to SPiCT but still significantly less optimistic than SPiCT) to a stock heavily depleted with both trend and absolutes values of the JABBA model considering both historical CPUE and technological creep to be very similar to those estimated by Stock Synthesis.

The issue is that with a possible fairly flat trend in CPUE covering only the last 20 years for a stock fished for more than a century, it is challenging to distinguish between two very different states of biomass depletion. In other words, the historical catches and the short CPUE entails alternative states, that a are hidden to current SPiCT runs. The outcomes of the JABBA models are also sensitive variance settings. On the other hand, the inclusion of information on size structure of the catches and life-trait history indicates a depleted stock. Another compelling evidence is obtained using JARA and trend analysis alone. In this case, depletion rate in 2020 is around 0.2–0.3 of 1974 levels (Figures 2.5.6 and 2.5.7), which is in line with results from SS. Finally, the historical catches and the normalized CPUEs are shown in Figures 2.5.8 and 2.5.9.

In summary, given the strong reliance on the potential spurious signal in the relative short CPUE indices that are currently not appropriately standardized, do not account for technological creeping, and considering that the fisheries for tusk in Northeast Atlantic started in the beginning of the 1900s or possibly before (i.e. tusk was already caught in large numbers within the Swedish longline fisheries for ling in the North Sea in 1860s; Cardinale *et al*., 2014), it is not possible with the available data fitted to SPMs to make robust conclusions about the status of the two stocks. Thus, there is the need for much more work for benchmarking the tusk stocks, ideally including fully standardized historical CPUE and size compositions data to "anchor" the stock status, and including different assumption for technological creep for the commercial CPUEs.

2.5.1 Conclusions

In the light of the SPiCT results presented at the benchmark, and considering the sensitivity analysis shown above, we suggest that both stocks remain in category 3 informed by a fully standardized commercial CPUE until an integrated model is developed. Standardisation should include spatio-temporal effect, and use different assumptions of technological creeping in the sensitivity analysis. Re-application of the SPiCT model using newly standardized commercial CPUEs could also be considered and compared with integrated model approaches.

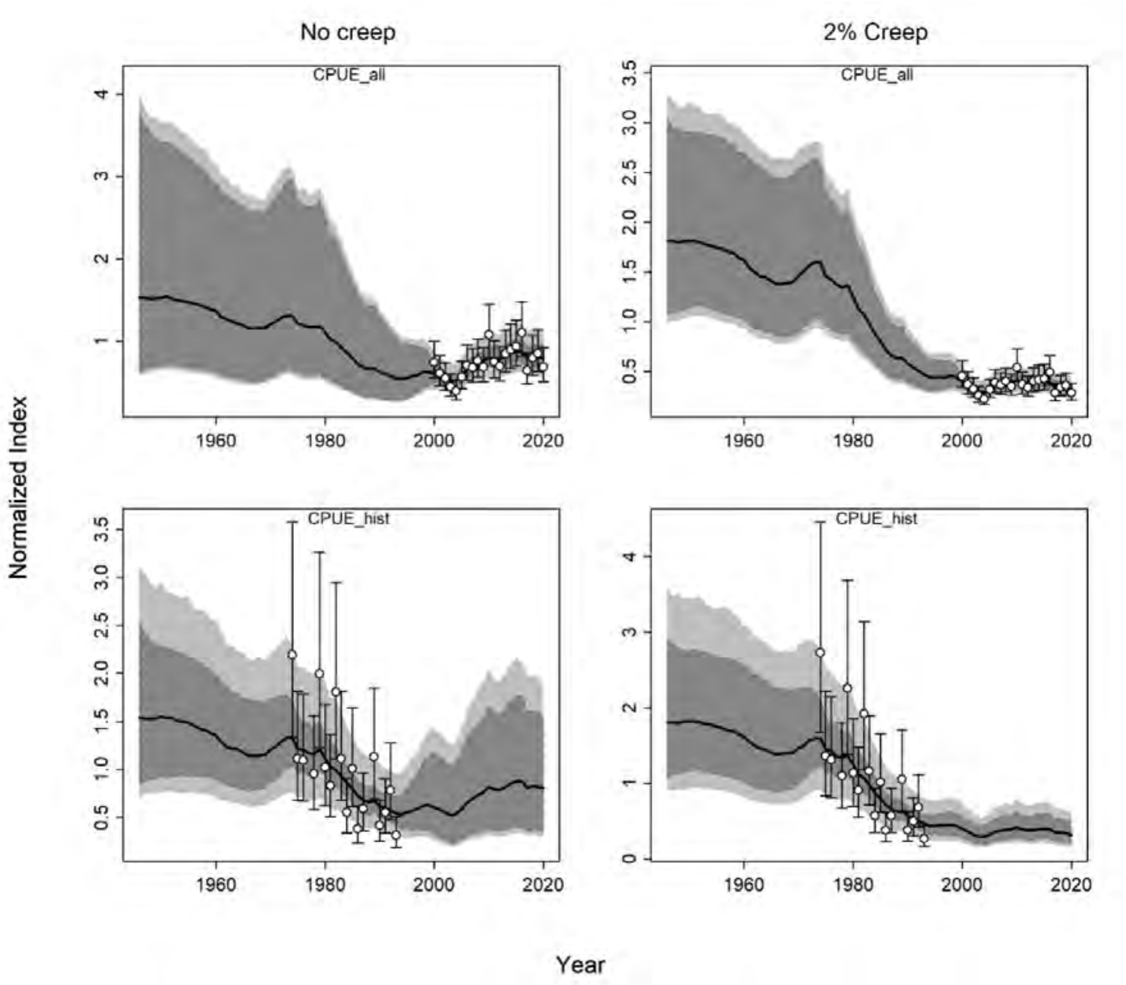

Figure 2.5.1. Arctic tusk. Fit of the JABBA models with the inclusion of the historical CPUE assuming no technological creep and 2% annual technological creep.

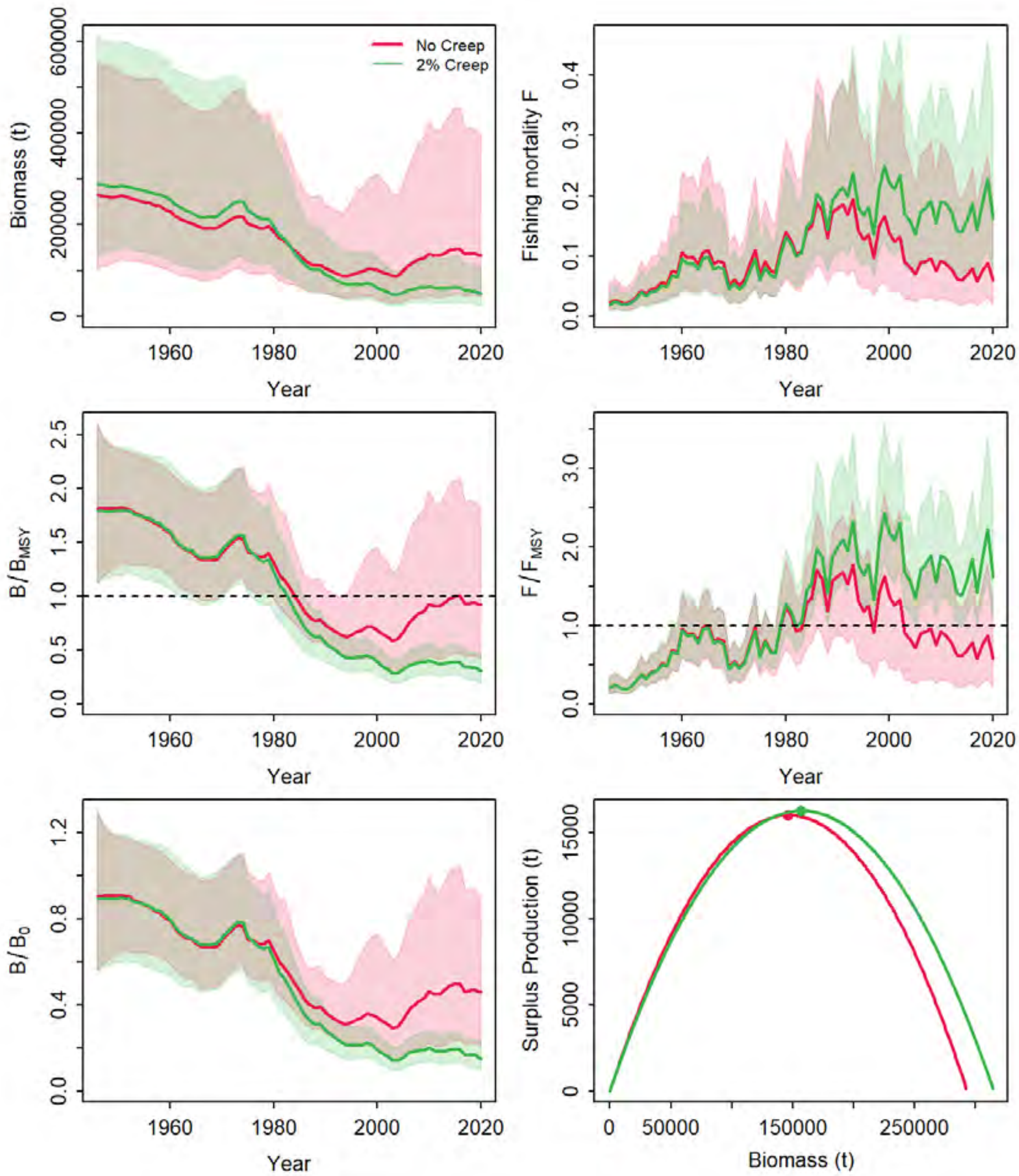

Figure 2.5.2. Arctic tusk. Stock summary of JABBA models with the inclusion of the historical CPUE assuming no technological creep and 2% annual technological creep.

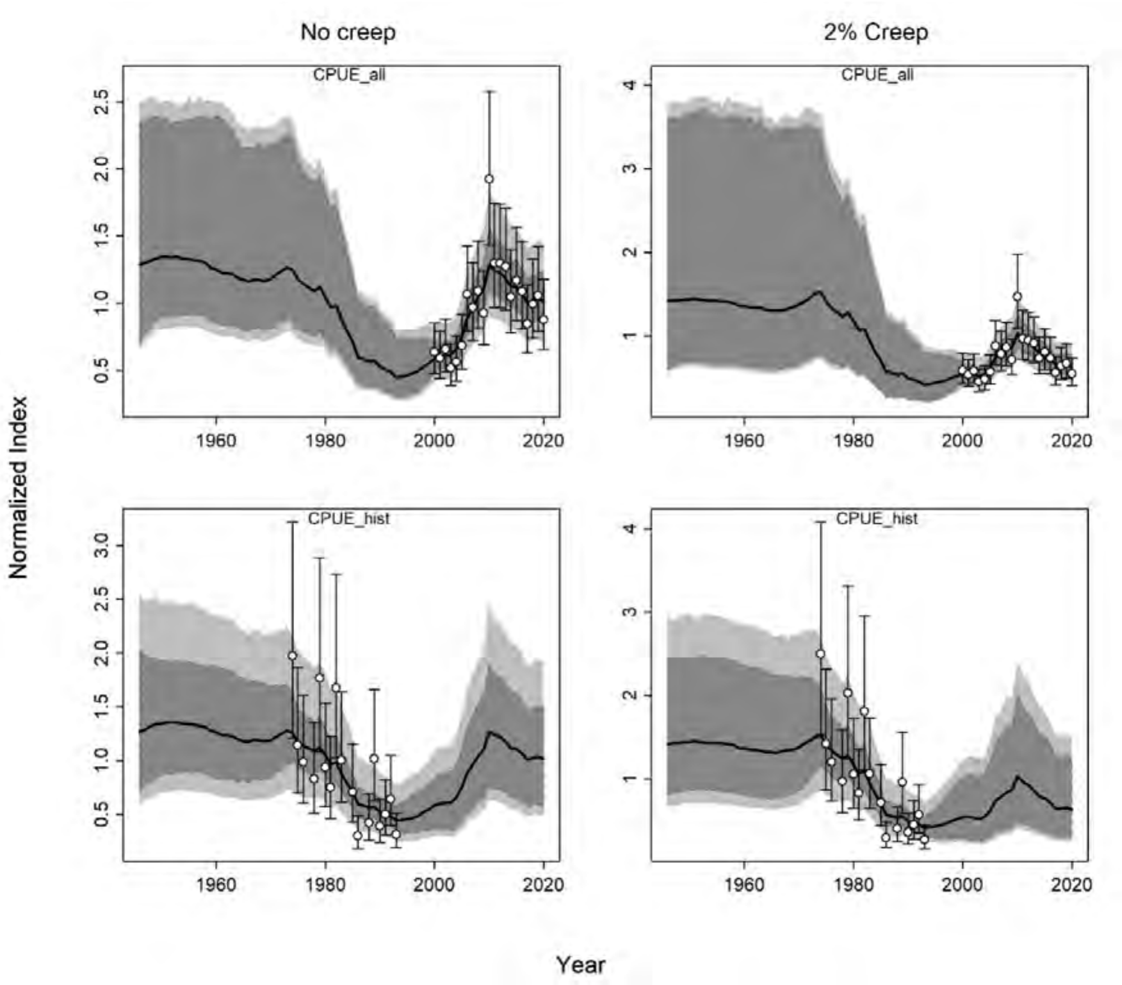

Figure 2.5.3. North Sea tusk. Fit of the JABBA models with the inclusion of the historical CPUE assuming no technological creep and 2% annual technological creep.

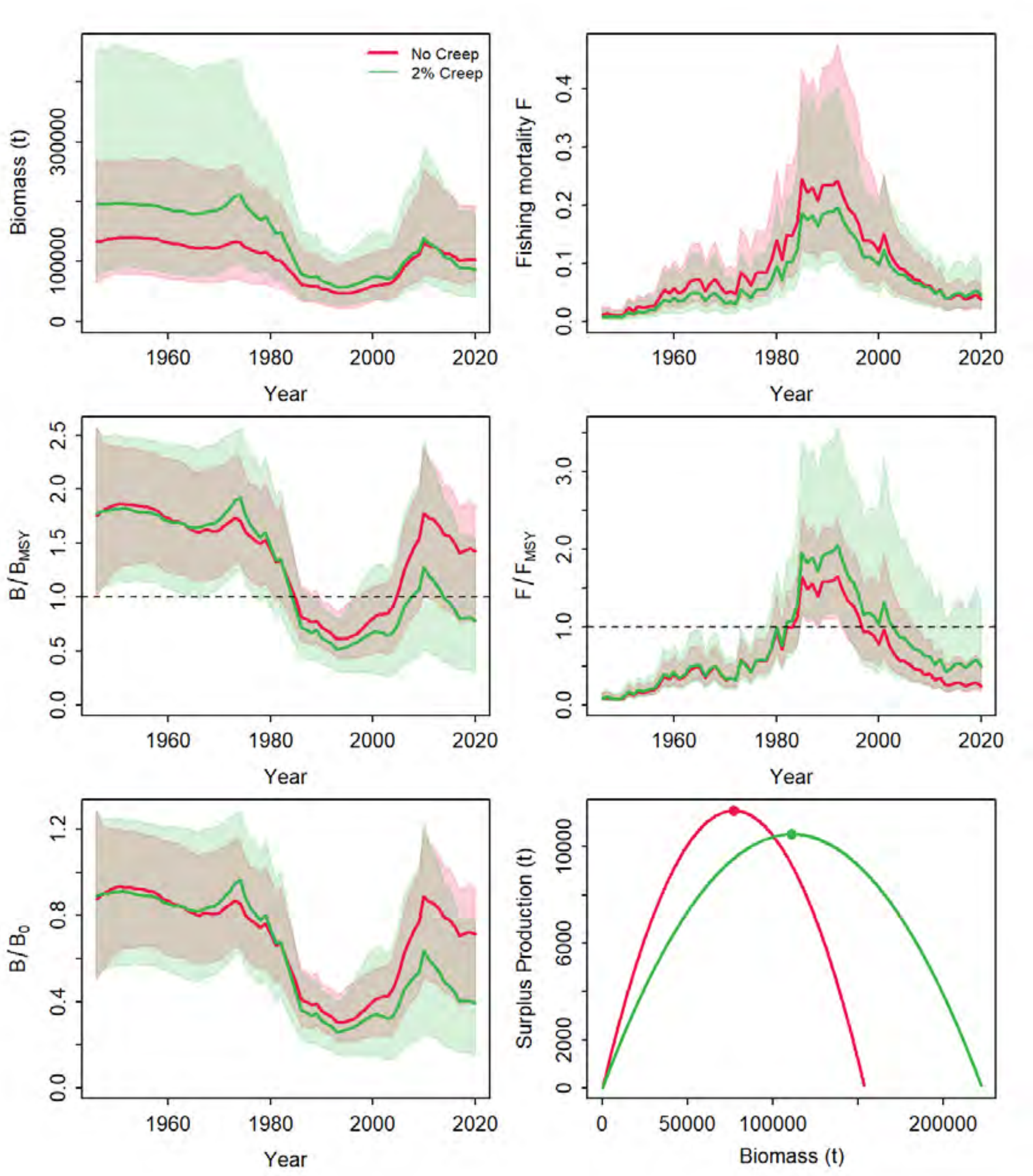

Figure 2.5.4. North Sea tusk. Stock summary of JABBA models with the inclusion of the historical CPUE assuming no technological creep and 2% annual technological creep.

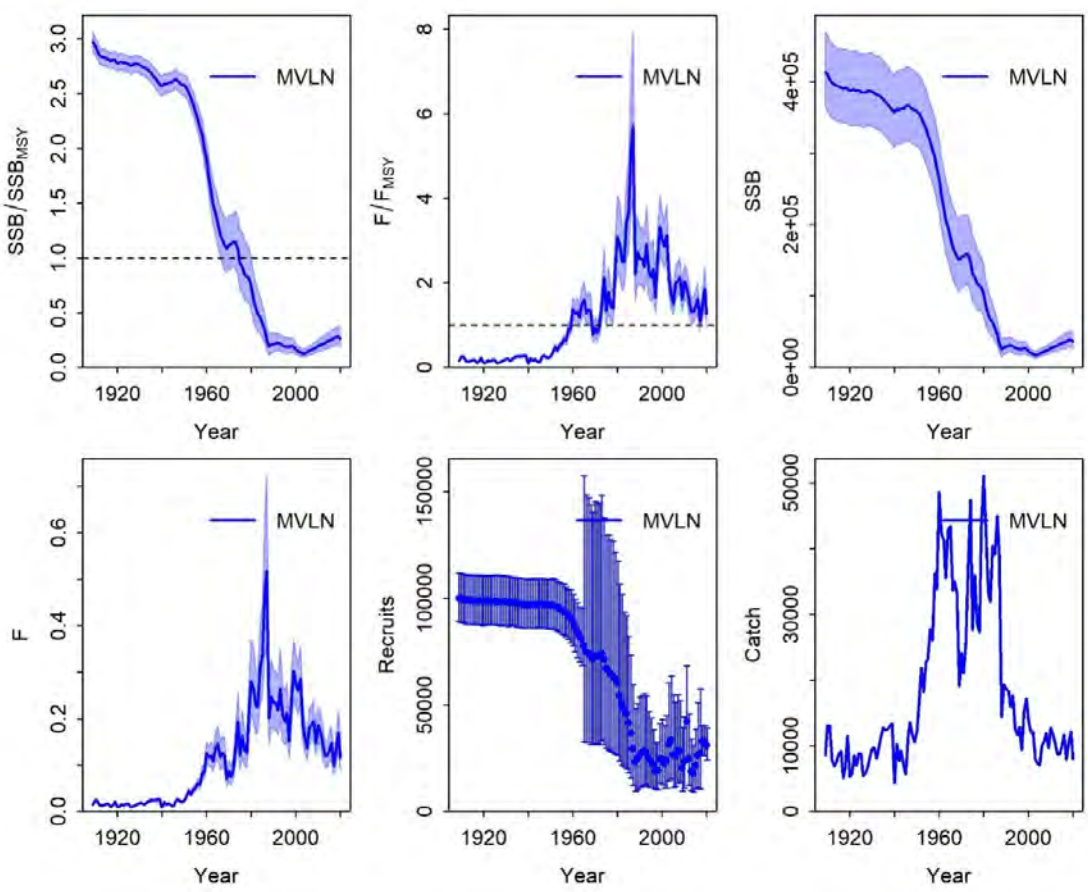

Figure 2.5.5. Arctic tusk. Stock summary of Stock synthesis models without the inclusion of the historical CPUE and assuming no technological creep for the modern CPUE.

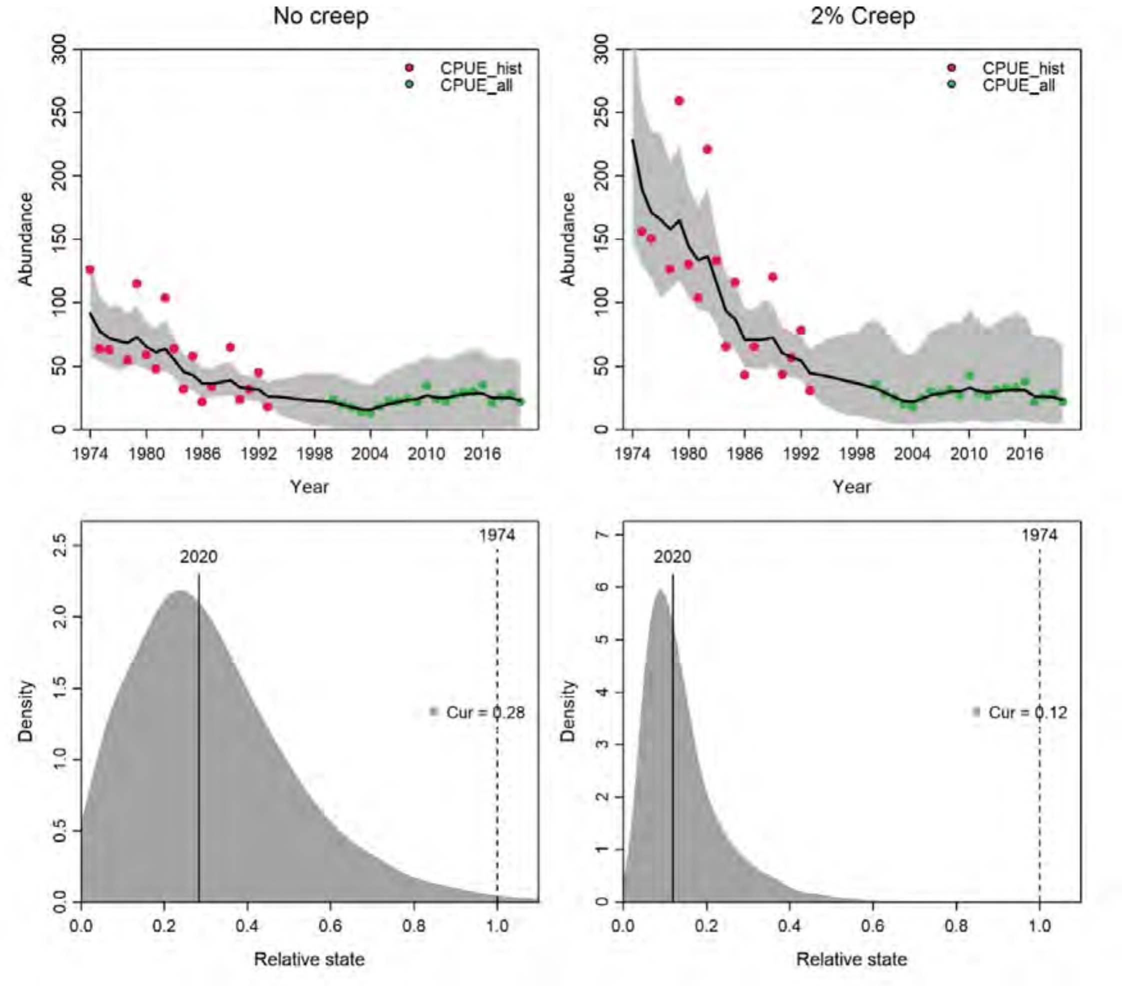

Figure 2.5.6. Arctic tusk. Results of the trend analysis using commercial CPUE for all vessels assuming no technological creep and 2% annual technological creep.

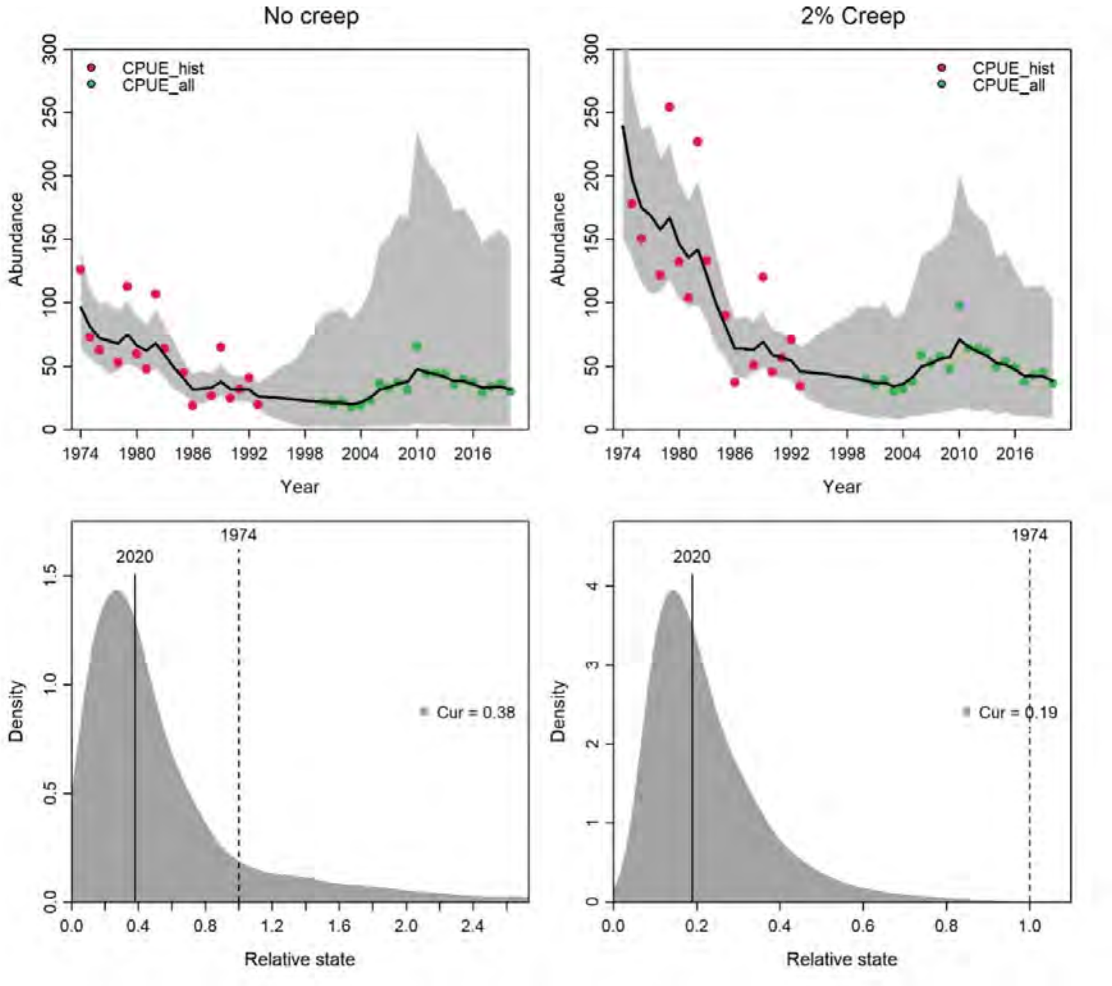

Figure 2.5.7. North Sea tusk. Results of the trend analysis using commercial CPUE for all vessels assuming no technological creep and 2% annual technological creep.

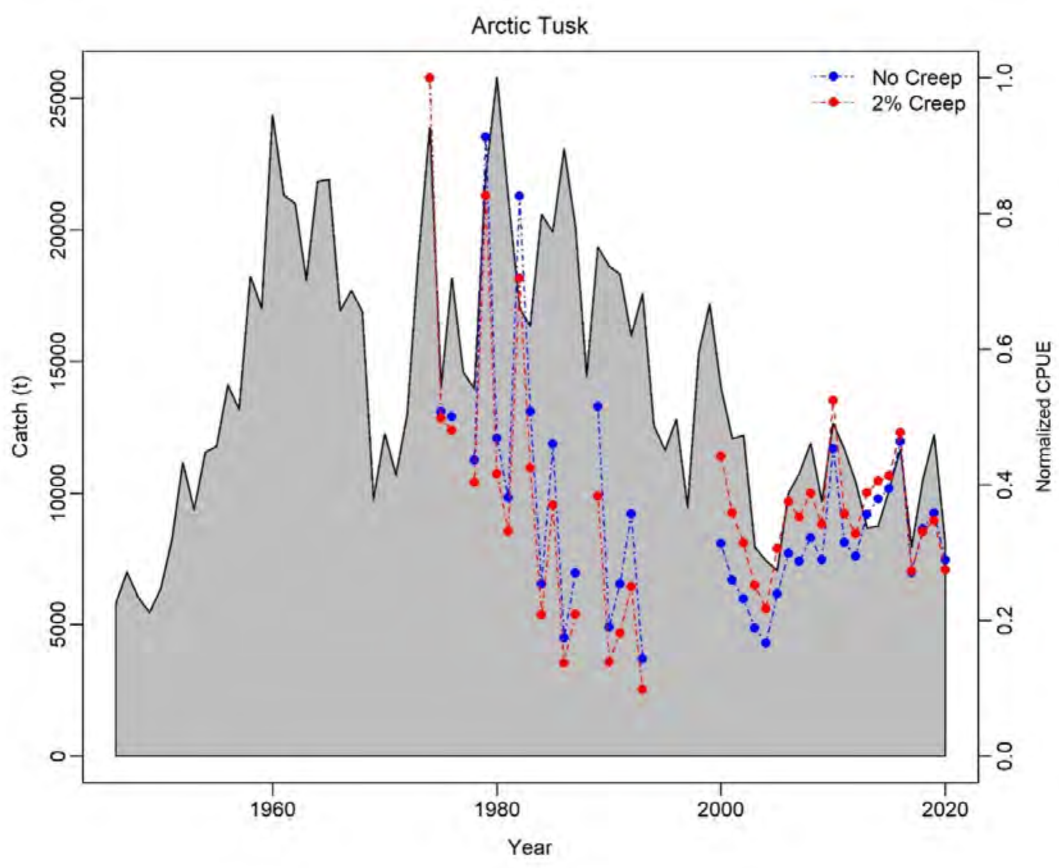

Figure 2.5.8. Arctic tusk. Commercial catches and normalized CPUEs of longlines vessel catching tusk.

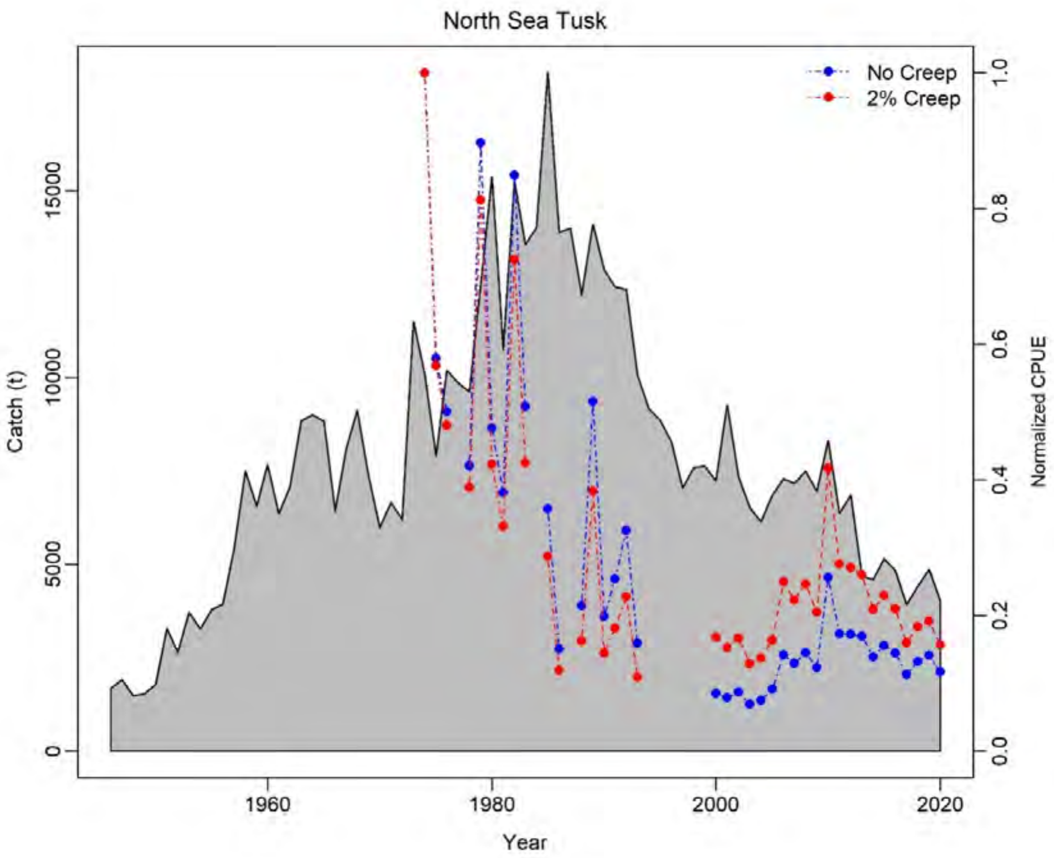

Figure 2.5.9. North Sea tusk. Commercial catches and normalized CPUEs of longlines vessel catching tusk.

2.6 References

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3 Tusk (*Brosme brosme*) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (usk.27.3a456a7–912)

3.1 Introduction

Tusk is bycatch in the trawl, gillnet and longline fisheries in areas 3.a, 4.a, 5.b, 6.a, 7, 8, 9 and 12. Norway has traditionally landed the major proportion of the landings. Around 90% of the Norwegian and Faroese landings are taken by longliners.

When landings are pooled over the period 1988–2019, 35% of the landings have been in Area 4, 47% in Area 5.b, and 17% in Area 6.a (ICES, 2020). Figure 3.1.1 shows the landings in 2013 reported by Norway, the Faroes, Iceland, France, UK (England and Wales) and Spain (ICES, 2014).

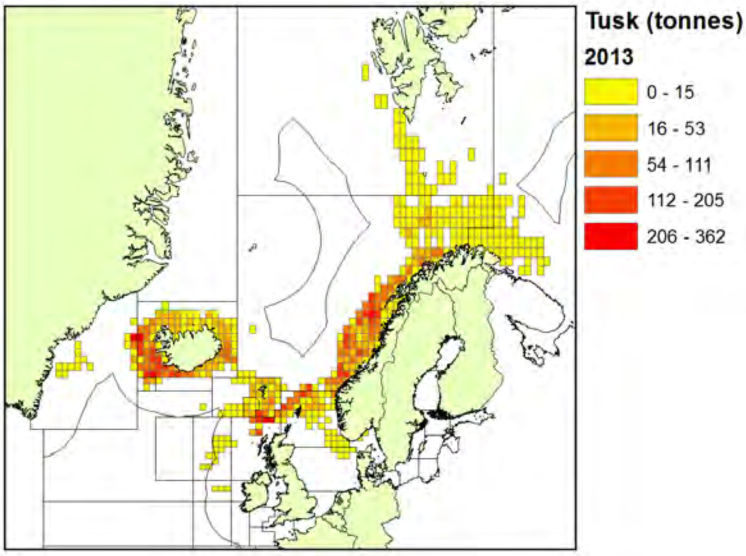

Figure 3.1.1. Reported landings of tusk in the ICES area by statistical rectangle in 2013. Data are from Norway, Faroes, Iceland, France, UK (England and Wales) and Spain. Landings shown in account for 99% of all reported landings in the ICES area (ICES, 2014).

In Subarea 4 tusk is mainly fished along the slope north of the Shetland Islands and in the deep trench along the coast of western Norway.

In Division 5.b, tusk is mainly fished by longliners (about 90% of the catch), and the rest of the catch of tusk was taken by large trawlers. The main fishing grounds for tusk are on the slope around the Faroes Plateau and on the Faroe Bank in areas deeper than approximately 200 m.

In Division 6.a, the fishery takes place on the slope west of the Hebrides.

Tusk is a bycatch species very often caught when ling is the target species. Figure 3.1.2 shows the proportion of catches of tusk in the Norwegian longline fishery divided between bycatch and targeted fishery. It appears that the proportion of tusk as bycatch has increased since 2000.

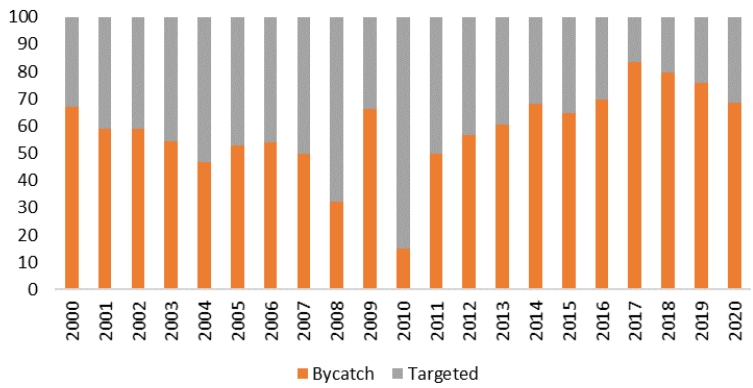

Figure 3.1.2. Proportion in percentage of catches of tusk divided between bycatch and targeted fishery.

The Norwegian longline fishery for tusk takes place from April to October. At the beginning and in the end of the year the longline fleet is fishing for cod and haddock along the coast of Northern Norway.

The main fishing area for the Norwegian longline fleet is Subarea 4a, followed by 5b and 6a. Only small catches were reported from area 4b. The landings in the different areas are given in Figure 3.1.3.

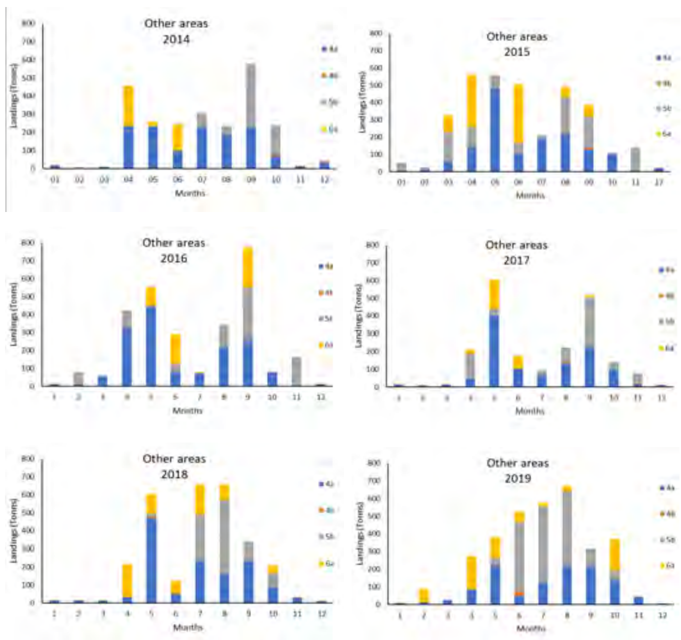

Figure 3.1.3. Monthly landings of tusk taken by the Norwegian longline fleet in the areas 4a, 4b, 5b and 6a during the years 2014–2019.

3.2 Input data for stock assessment (ToR 1 & 2)

3.2.1 Landings data

Landings were downloaded from the ICES database for the period 1950 to 2019. For 2020, preliminary landings were downloaded and estimated from the Norwegian Directorate of Fisheries.

In addition to landings reported by Norwegian and Faroese vessels also France, Great Britain, Denmark, Sweden, Germany, Ireland, and Spain report catches of tusk. Norway landed on average 61% of the total landings in these areas during the period 2014–2019.

The landings follow the same pattern as in subareas 1 and 2, low catches in the beginning of the series, a higher level of landings in the 1970s and 1980s, and then a reduction to the present levels of slightly below 5000 tons (Figure 3.2.1).

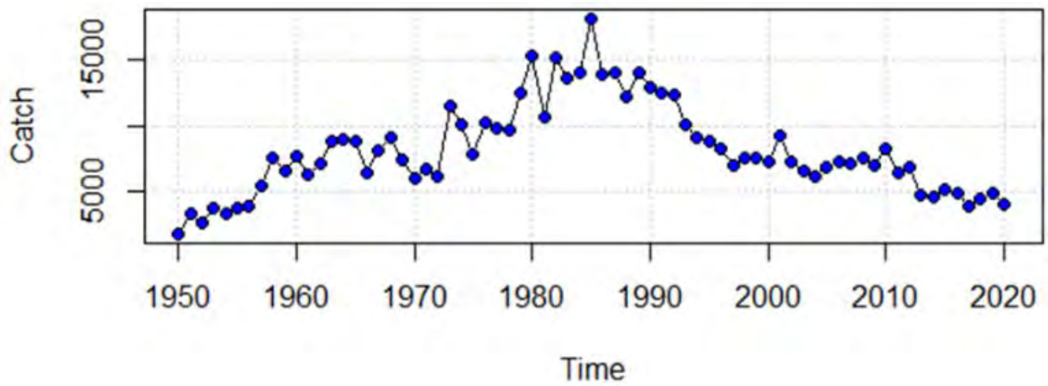

Figure 3.2.1. Catches of tusk from 1950 to 2020.

Shifts in technology, vessel types and regulations have taken place over the period from 1950 to 2020. These shifts should be taken into consideration when catches are used in any analysis. Especially for a bycatch species as tusk, the landings very likely show changes in the fishing activity rather than reflecting the status of the stock.

3.2.2 CPUE based on longline data

Norway started in 2003 to collect and enter data from official logbooks into an electronic database, and data are now available for 2000–2019. Vessels were selected that had a total landed catch of ling, tusk and blue ling exceeding 8 t in every year. The logbooks contain records of the daily catch, date, position, and number of hooks used per day. The quality of the Norwegian logbook data is poor in 2010, due to the switch from paper to electronic logbooks. Since 2011, data quality has improved considerably and data from the entire fleet were available.

The method used to calculate the CPUE series from the Norwegian longliners is described in Section 2.2.1 and in Helle *et al*. (2015). Two cpue series were made, one based on all data available and one based on sets where tusk made up more than 30% of the total catch.

WGDEEP decided some years ago to use the Norwegian longline CPUE series for the advice because it covers the «entire area», it was also decided to make one index for the entire area. Separate CPUE estimates for each subarea can be found in ICES. (2020). Results for the two indices are shown in Figure 3.2.2.

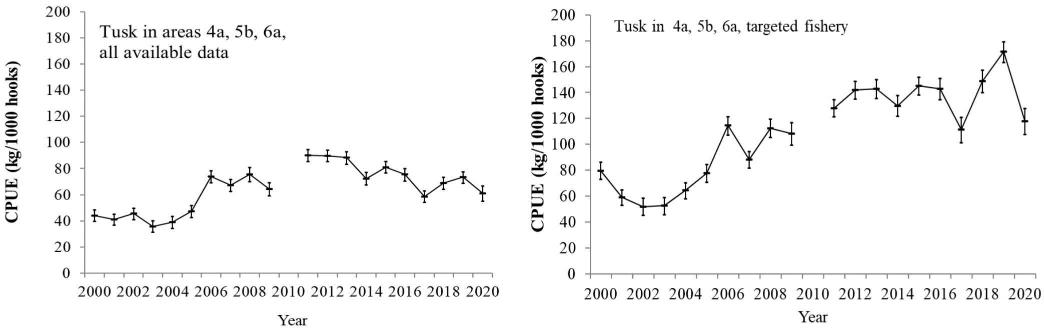

Figure 3.2.2. Estimates of cpue (kg/1000 hooks) of tusk based on skipper's logbook data for 2000–2020. The bars denote the 95% confidence interval.

3.3 Stock assessment (ToR 3)

It was not possible for the group to recommend or approve a SPiCT assessment for this stock. The reason for this was primarily the construction of the CPUE index; the CPUE index itself was not disregarded but it was not regarded suitable for the SPiCT model. Two points were pointed out as problematic; the targeting effect and technological creep, especially the targeting effect as different species compositions and different geographical spacing of the fishery between years.

The development in targeted CPUE index was regarded as unrealistic according to the steepness of the increase seen on a short period of time (ten years).

3.3.1 Exploratory assessments

The exploratory assessment shows the different trials we did before and at the benchmark meeting on the catch series and the two CPUE indices for this stock.

The recommendations from the data work group meeting was to run the assessments with long time-series on catches, run trials with both the targeted and allData CPUE series and to apply priors on n and B/K.

Two different CPUE indices were tried for the stock; one with all data available (allData) and one with data from the vessels that more than 30% of the catch was tusk (targeted), method is described in Helle *et al*. (2015). For landings data there were used long series from 1950, a medium long series from 1970 and a short series from 1988. The three different catch series were used together with the two CPUE series: all with several different settings for priors.

The process of work and fits to the model are described in Table 3.3.1.

When running the model with short time-series and both default settings and prior on n=2, convergence was succeeded with both index series. When extending the landing series back to 1950, no convergence was succeeded with default values for neither CPUE indices, for the series from 1970 there were no convergence for the default settings.

Different priors were applied trying to make the model converge. Primarily, the prior on n and B/K were used but also priors on logsdf, logsdc and logsdi were tried. Prior on logn was used when the production curve was skewed to left/right and prior on initial depletion level was used to inform the status of exploitation level in the beginning of the landing series. Since the fishery was at low levels before 1950, the initial depletion level was set to approximately 1.

The results from the runs with short landings series are not presented here since the recommendation from the group was clearly to use the longer dataseries. However, in Table 3.3.1, results from the three catch series are displayed.

3.3.1.1 Usk_other_target

Input data for tusk target are shown in Figure 3.3.1a. For the CPUE index, year 2010 was deleted because the quality of this datapoint was very poor. In 2010, only a small fraction of the vessels registered data in the database, and hence the CPUE from this year is not representative.

The working process is shown in Table 3.3.1. The production curve was right skewed from the scenario 4. Applied a prior on B/K=0.9 and when tighten the Shaeffer model by n=2, the production curve was still right skewed, so then tried to fix n=2 and the results from scenario number 5 and 6 were very similar (Table 3.3.1). The results for scenario 6 were chosen as the best fit and the results are shown as Figure 3.3.1b and Table 3.3.2.

All diagnostics tests were not significant (Figure 3.3.1c) and retrospective analysis was good (Figure 3.3.1d).

3.3.1.2 Usk_other_allData

Input data for tusk allData are shown in Figure3.3. 2a. Concerning the representativeness of CPUE in year 2010, this year was also deleted here.

The working process is shown in Table 3.3.1. No convergence was succeeded with default settings; then tried to apply priors on n and B/K and the convergence succeeded and the scenario 15 was chosen as the best fit (Figure 3.3.2b and Table 3.3.3).

All diagnostic tests were not significant (Figure 3.3.2c) and retrospective analysis was good (Figure 3.3.2d).

3.3.1.3 Comments on assessments

There were different opinions on this assessment from the reviewers as the assessment was not accepted. The stock assessors concluded on scenario 6, one reviewer concluded on scenario 15 as this option had less process error and looked more realistic than the other. The other reviewer commented on that the observed consistency in the results of the model was not reliable due to the problems with the input data and uncertainty in the CPUE series. Secondly, the results from both the trials showed unexpected high values of r (r=0.4–0.5) when expected 0.12 for tusk (SPM-priors from FishLife) (Table 3.3.4).

The assessments on SPiCT could not be approved according to the uncertainty in the CPUE index and due to the observed inconsistencies described above.

Table 3.3.1. Scenarios for working process and fits on tusk other areas.

	Scenarios	Landings	CPUE	Priors	Results
Tusk_other_targeted	1	1988–2020	2000–2020	Defaults	Convergence, production curve right skewed, diagnostics and retroplot ok
	2	1988–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1)	Convergence, production curve, diagnostics and retroplot ok
	3	1950–2020	2000–2020 (–2010)	Defaults	No convergence
	4	1950–2020	2000–2020 (–2010)	Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, production curve right skewed
	5	1950–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, production curve still right skewed
	6	1950–2020	2000–2020 (–2010)	Inpinilogn<-log(2) Inp$phases$logn<- -1 Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, production curve fixed n=2, diagnostics ok and retrospective ok
	7	1970	2000–2020 (–2010)	Defaults	No convergence
	8	1970	2000–2020 (–2010)	inp$priors$logn <-c(log(1.5),0.6,1) #Thorson et al(2012)	Convergence, produvtion curve to the right, good diagnostics, not good retro.
	9	1970	2000–2020 (–2010)	inp$priors$logbkfrac <-c(log(0.2),0.5,1)	Convergence, nice production curve, Diagnostics ok, not good retrospective.
	10	1970	2000–2020 (–2010)	inp$priors$logn <- c(log(2),0.5,1) # Tighter Schaeffer	Convergence, production curve slightly to the right, good diagnostics, perfect retro
Tusk_other_alldata	11	1988–2020	2000–2020	Defaults	Convergence, production curve right skewed, diagnostics and retro plot ok
	12	1988–2020	2000–2020	Inp$prior$logn<-c(log(2),0.5,1)	Convergence, production curve, diagnostics and retroplot ok

Scenarios	Landings	CPUE	Priors	Results
13	1950–2020	2000–2020 (–2010)	Defaults	No convergence
14	1950–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1)	No convergence, ok production curve
15	1950–2020	2000–2020 (–2010)	Inp$prior$logn<-c(log(2),0.5,1) Inp$prior$logbkfrac<-c(log(0.9),0.25,1)	Convergence, ok production curve, diagnostics and retrospective ok
16	1970	2000–2020 (–2010)	Defaults	No convergence
17	1970	2000–2020 (–2010)	inp$priors$logn <- c(log(2),0.5,1) # Tighter Schaeffer	Converge, nice production curve, nice diagnostics, and retro.
18	1970	2000–2020 (–2010)	inp$priors$logbkfrac <- c(log(0.2),0.5,1)	Converge, production curve slightly to the left, nice diagnostics, and retro.

Table 3.3.2. Scenario 6; output from the model.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: -7.6554102
Euler time step (years):  1/16 or 0.0625
Nobs C: 71,  Nobs I1: 20

Priors
  logalpha  ~  dnorm[log(1), 2^2]
   logbeta  ~  dnorm[log(1), 2^2]
 logbkfrac  ~  dnorm[log(0.9), 0.25^2]

Fixed parameters
   fixed.value
 n          2

Model parameter estimates w 95% CI
           estimate        cilow        ciupp    log.est
 alpha  5.521662e+00 4.170335e-01 7.310864e+01  1.7086789
 beta   6.953002e-01 4.214035e-01 1.147220e+00 -0.3634116
 r      4.502376e-01 3.022270e-01 6.707337e-01 -0.7979799
 rc     4.502376e-01 3.022270e-01 6.707337e-01 -0.7979799
 rold   4.502376e-01 3.022270e-01 6.707337e-01 -0.7979799
 m      1.109958e+04 1.017124e+04 1.211266e+04  9.3146629
 K      9.861091e+04 6.934328e+04 1.402315e+05 11.4989372
 q      1.730200e-03 1.248000e-03 2.398900e-03 -6.3594921
 sdb    2.880220e-02 2.489900e-03 3.331692e-01 -3.5473036
 sdf    1.608340e-01 1.170539e-01 2.209885e-01 -1.8273826
 sdi    1.590360e-01 1.118776e-01 2.260726e-01 -1.8386247
 sdc    1.118279e-01 8.386840e-02 1.491083e-01 -2.1907943

Deterministic reference points (Drp)
          estimate        cilow        ciupp   log.est
 Bmsyd 4.930546e+04 3.467164e+04 7.011575e+04 10.805790
 Fmsyd 2.251188e-01 1.511135e-01 3.353669e-01 -1.491127
 MSYd  1.109958e+04 1.017124e+04 1.211266e+04  9.314663
Stochastic reference points (Srp)
          estimate        cilow        ciupp   log.est
 Bmsys 4.924778e+04 34605.208576 7.008610e+04 10.804620
 Fmsys 2.249147e-01     0.151011 3.349865e-01 -1.492034
 MSYs  1.107654e+04 10130.697178 1.211069e+04  9.312585
        rel.diff.Drp
 Bmsys -0.0011711411
 Fmsys -0.0009073545
 MSYs  -0.0020805244

States w 95% CI (inp$msytype: s)
                    estimate        cilow        ciupp
 B_2020.94      8.542603e+04 6.098442e+04 1.196634e+05
 F_2020.94      4.888150e-02 3.186170e-02 7.499290e-02
 B_2020.94/Bmsy 1.734617e+00 1.585143e+00 1.898185e+00
 F_2020.94/Fmsy 2.173333e-01 1.584261e-01 2.981438e-01
                   log.est
 B_2020.94      11.3554061
 F_2020.94      -3.0183572
 B_2020.94/Bmsy  0.5507865
 F_2020.94/Fmsy -1.5263232

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp
 B_2022.00      8.624772e+04 6.147604e+04 1.210011e+05
 F_2022.00      4.888160e-02 2.856080e-02 8.366050e-02
 B_2022.00/Bmsy 1.751302e+00 1.610943e+00 1.903889e+00
 F_2022.00/Fmsy 2.173340e-01 1.381143e-01 3.419928e-01
 Catch_2021.00  4.197294e+03 3.033297e+03 5.807964e+03
 E(B_inf)       8.771330e+04           NA           NA
```

```
               log.est
B_2022.00       11.3649789
F_2022.00       -3.0183537
B_2022.00/Bmsy  0.5603593
F_2022.00/Fmsy -1.5263198
Catch_2021.00   8.3421954
E(B_inf)        11.3818289
```

Table 3.3.3. Scenario 15; output from the model

```
Convergence: 0  MSG: both X-convergence and relative convergence (5)
Objective function at optimum: -12.3249758
Euler time step (years):  1/16 or 0.0625
Nobs C: 71,  Nobs I1: 20

Priors
     logn  ~  dnorm[log(2), 0.5^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]
logbkfrac  ~  dnorm[log(0.9), 0.25^2]

Model parameter estimates w 95% CI
          estimate        cilow        ciupp     log.est
alpha  6.951560e-01 1.793607e-01 2.694246e+00 -0.3636190
beta   7.423338e-01 4.237883e-01 1.300318e+00 -0.2979563
r      5.116001e-01 2.014405e-01 1.299315e+00 -0.6702120
rc     4.708127e-01 1.720325e-01 1.288504e+00 -0.7532950
rold   4.360485e-01 9.079830e-02 2.094073e+00 -0.8300017
m      1.189831e+04 8.884850e+03 1.593385e+04  9.3841518
K      9.794809e+04 4.151642e+04 2.310852e+05 11.4921929
q      8.767000e-04 3.582000e-04 2.145600e-03 -7.0393541
n      2.173264e+00 8.694546e-01 5.432230e+00  0.7762302
sdb    1.273340e-01 6.631810e-02 2.444877e-01 -2.0609417
sdf    1.421054e-01 9.905600e-02 2.038639e-01 -1.9511861
sdi    8.851700e-02 3.812200e-02 2.055310e-01 -2.4245607
sdc    1.054897e-01 7.527720e-02 1.478278e-01 -2.2491424

Deterministic reference points (Drp)
          estimate        cilow        ciupp    log.est
Bmsyd 5.054372e+04 1.879391e+04 1.359306e+05 10.830594
Fmsyd 2.354063e-01 8.601630e-02 6.442518e-01 -1.446442
MSYd  1.189831e+04 8.884850e+03 1.593385e+04  9.384152
Stochastic reference points (Srp)
          estimate        cilow        ciupp    log.est
Bmsys 4.940290e+04 1.841434e+04 1.325406e+05 10.807764
Fmsys 2.307352e-01 8.233750e-02 6.465909e-01 -1.466485
MSYs  1.139366e+04 8.546555e+03 1.518921e+04  9.340812
       rel.diff.Drp
Bmsys  -0.02309212
Fmsys  -0.02024453
MSYs   -0.04429254

States w 95% CI (inp$msytype: s)
                   estimate        cilow        ciupp
B_2020.94      7.517181e+04 2.997898e+04 1.884921e+05
F_2020.94      5.477960e-02 2.145670e-02 1.398538e-01
B_2020.94/Bmsy 1.521607e+00 1.044769e+00 2.216076e+00
F_2020.94/Fmsy 2.374135e-01 1.291990e-01 4.362661e-01
                 log.est
B_2020.94      11.227531
F_2020.94      -2.904437
B_2020.94/Bmsy  0.419767
F_2020.94/Fmsy -1.437952

Predictions w 95% CI (inp$msytype: s)
                 prediction        cilow        ciupp
```

```
B_2022.00      7.880349e+04 3.205728e+04 1.937155e+05
F_2022.00      5.477980e-02 2.055410e-02 1.459966e-01
B_2022.00/Bmsy 1.595119e+00 1.077716e+00 2.360921e+00
F_2022.00/Fmsy 2.374142e-01 1.211494e-01 4.652561e-01
Catch_2021.00  4.223796e+03 3.006419e+03 5.934121e+03
E(B_inf)       8.362946e+04           NA           NA
                  log.est
B_2022.00      11.2747125
F_2022.00      -2.9044337
B_2022.00/Bmsy  0.4669481
F_2022.00/Fmsy -1.4379489
Catch_2021.00   8.3484896
E(B_inf)       11.3341511
```

Table 3.3.4. Result table for tusk other targeted and allData.

	B_{MSY}	F_{MSY}	MSY	B/B_{MSY}	F/F_{MSY}	r	K
Scenario 6	49248	0.22	11077	1.73	0.22	0.45	98611
Scenario 15	49403	0.23	11394	1.52	0.24	0.51	97948

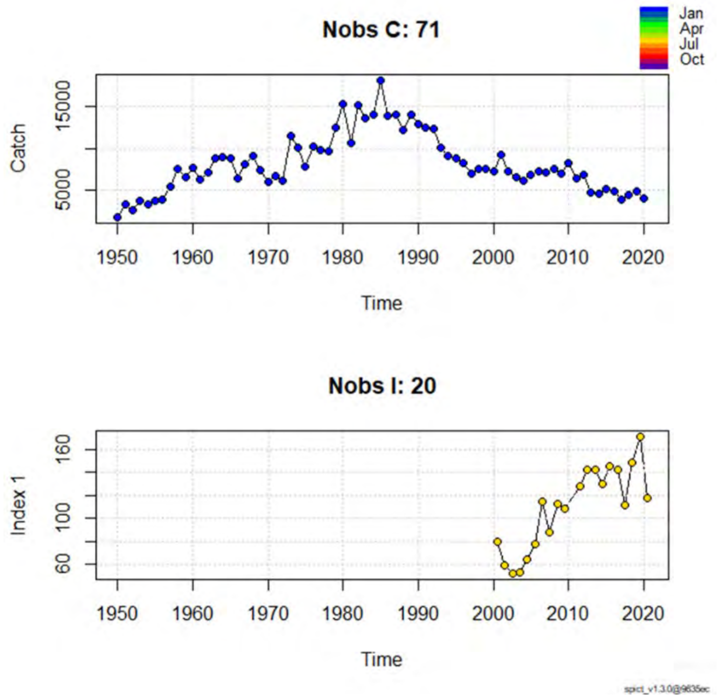

Figure 3.3.1a. Input data for tusk other targeted.

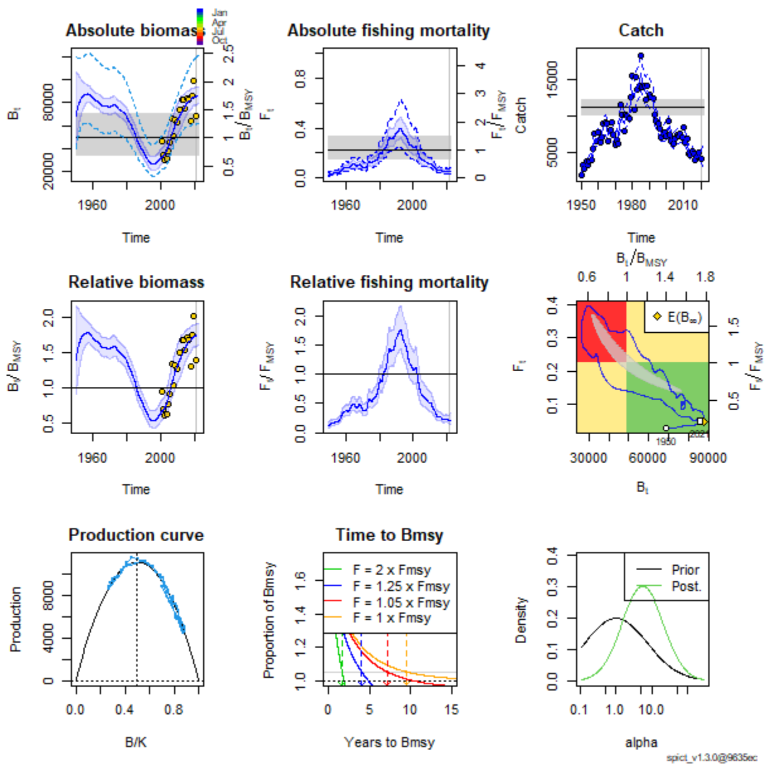

Figure 3.3.1b. Result plots for tusk scenario 6.

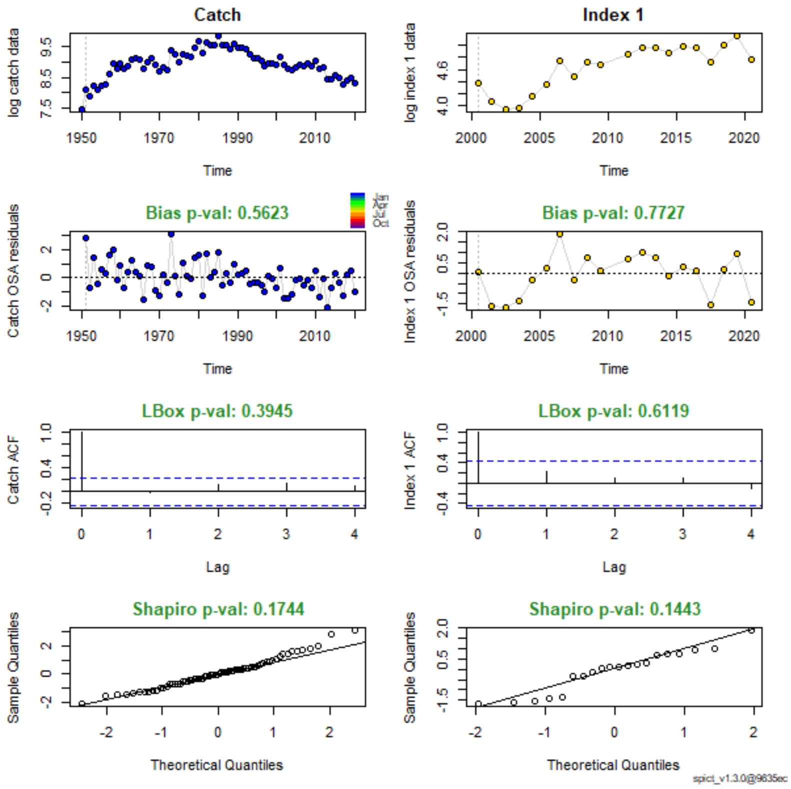

Figure 3.3.1c. Diagnostic plots for tusk scenario 6.

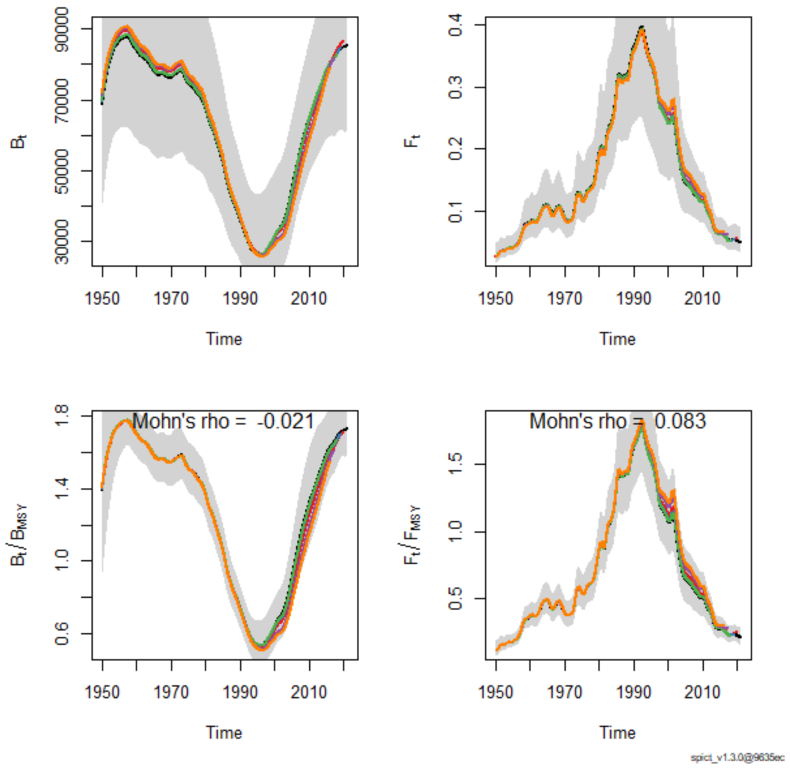

Figure 3.3.1d. Retrospective plots for tusk scenario 6.

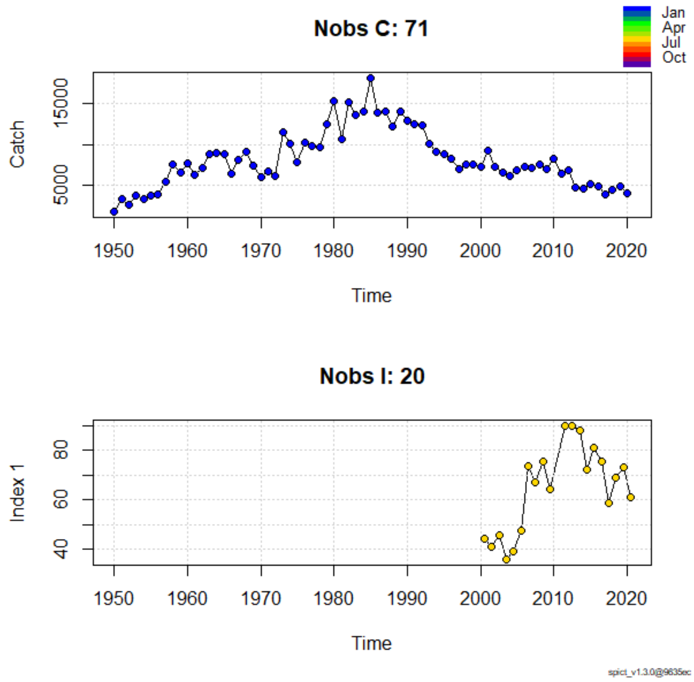

Figure 3.3.2a. Input data for tusk other allData.

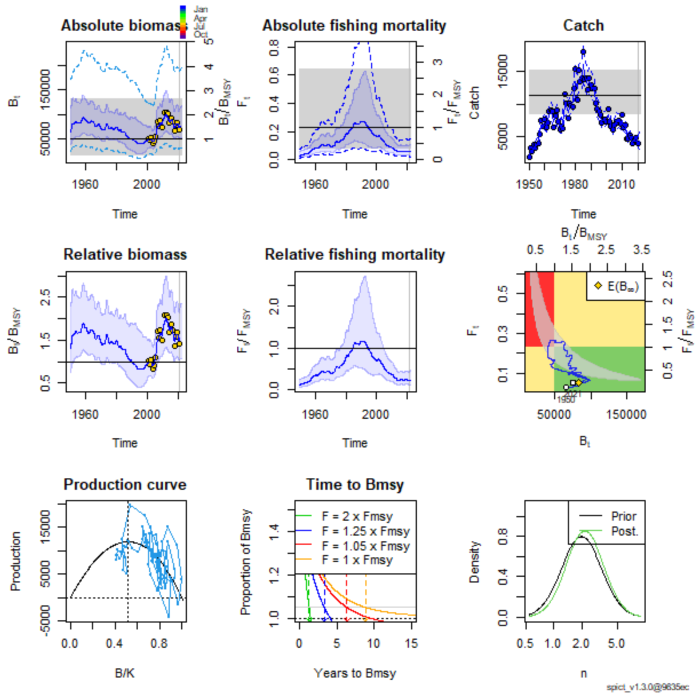

Figure 3.3.2b. Result plots for tusk scenario 15.

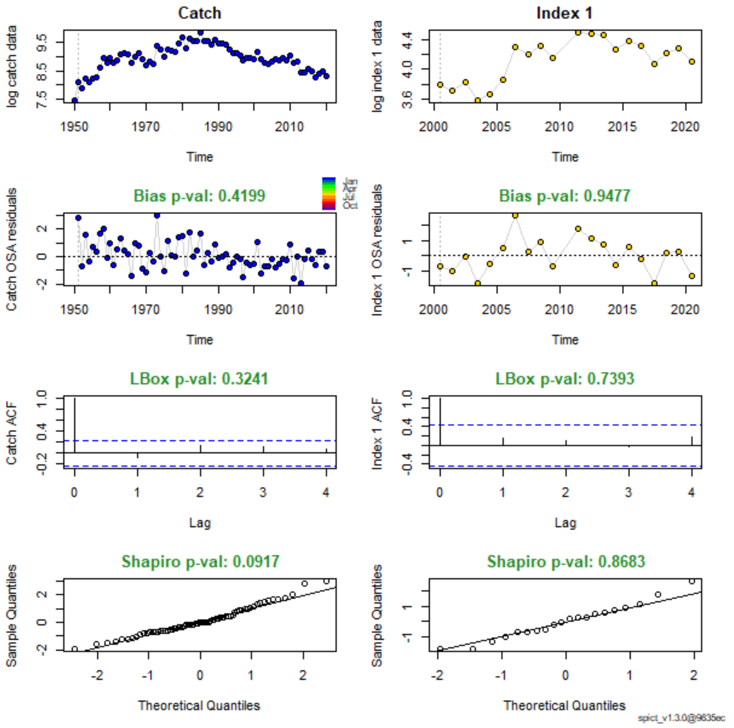

Figure 3.3.2c. Diagnostic plots for tusk scenario 15.

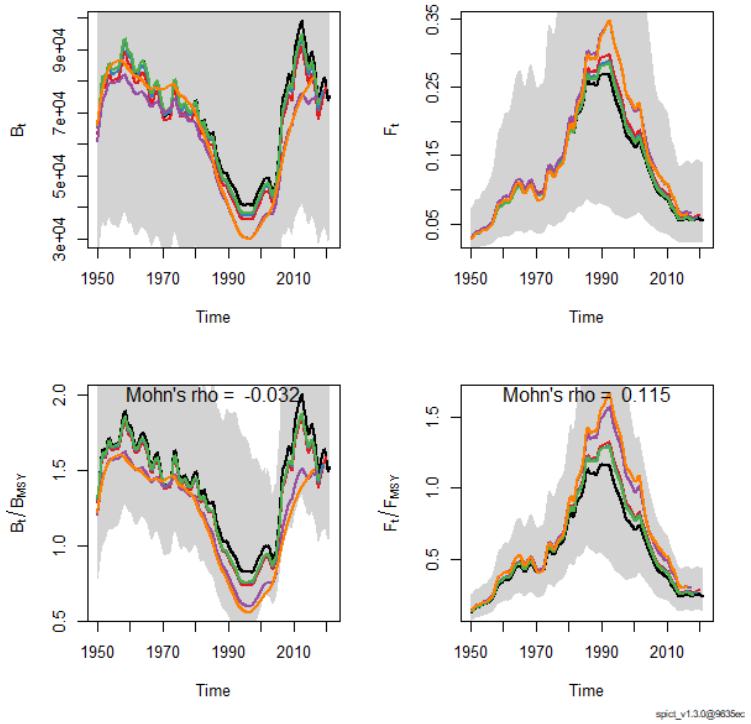

Figure 3.3.2d. Retrospective plots for tusk scenario 15.

3.4 Future considerations/ recommendations

If using SPiCT for future assessment, the CPUE index must be constructed to better incorporate the effects of targeting, zero-catches and technological creep.

Since there are data available on length compositions the use of other integrated models should be considered. However, input data should be quality controlled as the life history parameters are highly uncertain.

It is recommended that the assessment for tusk in this area is using the 3.2 rule advice until there is an assessment using SPiCT or other integrated models available.

3.5 Reviewers report

Reviewers report was made for both tusk stocks and incorporated in Section 2.5.

3.6 References

Helle, K., M. Pennington, N-R. Hareide and I. Fossen. 2015. Selecting a subset of the commercial catch data for estimating catch per unit effort series for Ling (*Molva molva* L.). Fisheries Research 165: 115–120. https://doi.org/10.1016/j.fishres.2014.12.015.

ICES. 2014. Report of the Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources (WGDEEP). ICES CM 2014/ ACOM:17, 863 pp.

ICES. 2020. Working Group on the Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP). ICES Scientific Reports. 2:38. 928pp. http://doi.org/10.17895/ices.pub.6015.

4 Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall) (lez.27.6b)

4.1 Introduction

Megrim stock structure is uncertain; with populations in 6.a and 6.b considered as separate stocks. Data described by Gordon (2001) indicated the distribution and biology of Megrim in West of Scotland waters, exhibited significant differences in growth parameters and population structures. WKFLAT concluded that megrim in 6.b should be considered as a separate stock until further information is available (ICES, 2011). The migratory behaviour of megrim is poorly understood; their biology suggests they can be relatively mobile in comparison to other flatfish species. However, there is little evidence to suggest that megrim migrate across the Rockall trough, with depths of 3000 m in places; this would suggest a natural barrier to a species with a bathymetric range of ~800 m (ICES, 2006).

Megrim are predominately taken in otter trawls. Analysis of VMS data indicates that megrim are taken in spatially discrete shelf fisheries and also in trawl fisheries conducted along the 200 m shelf break. Historically, ICES has assumed that megrim catches are closely linked to those of monkfish and haddock and more recently to cephalopod fisheries in subarea 6.b.

The introduction of the Cod Long-Term Management Plan (EC, 2008) and additional emergency measures applicable to 6.a in 2009 has impacted on the amount of effort deployed and increased the gear selectivity pattern of the main otter trawl fleets. Ireland had the highest catches in 2019 followed by Scotland and Spain. The majority of the landings and catches are from otter trawls.

4.2 Input data for stock assessment (ToR 1 & 2)

Catch data

Catches of megrim comprise two species, *Lepidorhombus whiffiagonis* and *L. boscii*. Information available to the Celtic Sea Working Group indicates that *L. boscii*, are a negligible proportion of the Scottish and Irish megrim catch (Gordon, 2001; Kunzlik *et al.*, 1995). Official landings for each country together with Working Group best estimates of landings from 6.b are shown in (Table 4.1). The WG best estimates of landings are the same as the official statistics.

Table 4.1. Megrim in Subarea 6.b. Nominal catch (t) of Lez.27.6b, as officially reported to ICES and WG best estimates of landings (tonnes) *

Year	Belgium	France	Ireland	Spain	UK – Eng+Wales+N.Irl.	UK – England & Wales	UK – Scotland	UK	Official total	ICES landings	ICES Discards
1991			240	587	14		204		1045	1045	
1992			139	683	53		198		1073	1073	
1993			128	594	56		147		925	925	
1994			176	574	38		258		1046	1046	
1995			117	520	27		152		816	816	
1996			124	515	92		112		843	843	
1997			141	628	76		164		1009	1009	
1998			218	549	116		208		1091	1091	
1999			127	404	57		278		866	866	
2000		4	167	427	57		309		964	964	
2001		< 0.5	176	370	42		236		824	824	
2002		< 0.5	87	120	41		207		455	455	
2003			83	93	74		382		632	632	
2004			43	71	42		372		528	528	
2005			68	88	19		207		382	382	87
2006			95	59	9		181		344	344	75
2007			87	19					106	106	22
2008			68	84		1	141		294	294	59
2009			48	0			178		226	226	44
2010			47	0				92	139	139	26
2011			72	17				66	155	155	7
2012			120	15				89	224	224	21
2013			181	39				58	278	278	15
2014			230	18				95	343	343	15
2015			256	67				130	453	453	85
2016			272	27				106	405	405	145
2017			358	46	15		167		586	586	233
2018			438	62	14		249		763	763	203
2019			452	82			223		783	783	34

*** Official landings data from ICES (ICES, 2019a).**

Survey data

The Fisheries Research Services (FRS), designed the SIAMISS (Scottish Irish Anglerfish Megrim Industry Science Survey) in 2005 to estimate the absolute abundance and distribution of anglerfish on the Northern Shelf (ICES, 2009). The survey area has been stratified based on knowledge from fishermen with sampling effort within each stratum allocated roughly according to its expected biomass.

Surveys are carried out on an annual basis usually in the spring. The survey is also considered to have greater spatial coverage for megrim, and as such was recommended by WKAGME as the main source of data of megrim relative biomass, on the Northern Shelf (ICES, 2009).

A more in-depth description of the SIAMISS survey can be found in the WGCSE report on Anglerfish (*Lophius budegassa*, *Lophius piscatorius*) in subareas 4 and 6 and in Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat) (ICES, 2020).

The survey index for 6.b is presented in Table 4.2. Biomass and abundance recovery have continued in 2019 after a prior reduction in 2017. The stock has displayed a largely increasing abundance and biomass trend since 2005. The area-stratified survey provides a minimum estimate of absolute biomass; survey catches are raised based on swept area and weighted by area. The survey assumes that all megrim in the trawl path are retained e.g. q=1. Assuming full retention is overly optimistic, therefore the minimum estimate of stock biomass was provided. The biomass dynamic model used in the Lez.27.4a6a assessment, provided megrim catchability estimates of 0.2–0.3 for SAIMISS-Q2/IAMISS-Q2 6.a and 4.a surveys (ICES, 2020). The upper q estimate of 0.3 is used in combination to scale the survey biomass estimate. This provides an absolute biomass and catch estimate offering a relatively broad harvest ratio approximation of megrim in 6.b (Table 4.2). This indicates the harvest ratio for megrim ranges from 2 to 25% over the time-series; however, in recent years, this value has typically been less than 10%.

Table 4.1. Estimates of Lez.27.6b biomass and harvest ratio from SAMISS surveys.

Year	Survey Biomass (tonnes)	Survey q	Raised Biomass (tonnes)	Landings (tonnes)	Discards (tonnes)	Catch (tonnes)	Harvest Ratio
2005	566	0.3	1886	382	87	469	0.25
2006	929	0.3	3098	344	75	419	0.14
2007	1267	0.3	4224	106	22	128	0.03
2008	1728	0.3	5759	294	59	353	0.06
2009	1605	0.3	5349	226	44	270	0.05
2010	1991	0.3	6636	139	26	165	0.02
2011	885	0.3	2949	155	7	162	0.05
2012	4320	0.3	14 401	224	21	245	0.02
2013	3030	0.3	10 101	278	15	293	0.03
2014	3318	0.3	11 060	343	15	358	0.03
2015	3262	0.3	10 872	453	85	538	0.05
2016	4507	0.3	15 024	405	145	550	0.04
2017	3015	0.3	10 067	586	233	819	0.08
2018	3984	0.3	13 280	763	203	967	1.13
2019	4150	0.3	13835	783	34	817	–

The addition of lez4a6a survey data as possible biomass indices to the lez6b assessment was discussed at the data evaluation workshop (17–19 November 2020). After consultation with colleagues, the general consensus was not to use the survey indices, as they don't apply to lez6b. An Alternative option was to investigate a lez6b LPUE using Irish catch data (Table 4.3). A course LPUE (lez6b OTB) was explored. The LPUE would need additional testing and standardisation; exploratory runs are described in Section 4.3.1.

Table 4.2. Megrim LPUE data subarea 6.b.

Year	Landings tonnes	Effort ('000s Hrs)	LPUE Kg/Hr
1995	139.19	9.14	15.22
1996	122.55	7.22	16.98
1997	140.19	7.17	19.55
1998	206.62	7.34	28.16
1999	134.45	8.68	15.49
2000	157.19	9.88	15.90
2001	172.03	7.23	23.79
2002	83.47	2.63	31.79
2003	81.71	4.54	17.99
2004	46.47	2.23	20.81
2005	41.52	3.28	12.65
2006	103.06	5.90	17.47
2007	87.50	6.59	13.28
2008	70.00	9.90	7.07
2009	50.04	4.35	11.50
2010	51.03	3.28	15.56
2011	70.25	2.53	27.72
2012	123.03	3.25	37.88
2013	189.39	3.81	49.72
2014	209.08	4.16	50.28
2015	264.02	4.75	55.61
2016	275.13	6.19	44.46
2017	363.00	14.89	24.38
2018	454.82	11.78	38.60
2019	472.86	17.24	27.42

Historic catch data

The option of assessing a longer catch time-series was also explored. Data from ICES historical catch statistics (Lassen; H.; Cross; D.; Christiansen, E., 2012) were extracted. Megrim data from Subarea 6.b are shown in Figure 4.1.

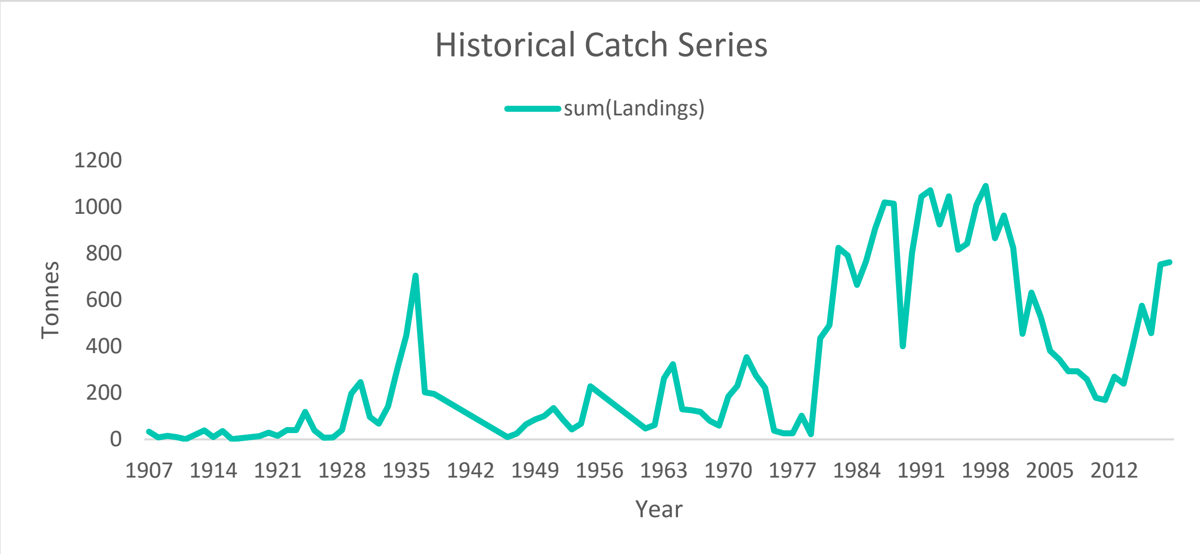

Figure 4.1. Historical catch statistic data for megrim in Subarea 6.b.

4.3 Stock assessment (ToR 3)

4.3.1 Exploratory assessments

LPUE Run

The results from the aforementioned model run can be seen in Table 4.4. Overall the addition of the LPUE did not cause much disruption to the earlier model runs using the original lez6b assessment inputs, namely catch data from 1991 and survey data from 2005. The assessment used a prior for growth rate (r). Given that r is not directly estimated for this stock, a secondary source was used to acquire it. The FishLife package predicts life-history parameters from life-history correlations and taxonomic similarities among species (Thorson *et al*., 2017). The life-history information used by FishLife comes from FishBase. Although FishLife allows to include particular life-history data, this option was not used in Megrim 6.b. Both, estimate and standard deviation of r, which are expressed in terms of natural logarithm for *Lepidorhombus whiffiagonis* were used to set the r prior in SPiCT (Table 4.4). The model converged (Figure 4.2); however, there were some autocorrelation issues with the LPUE data (Figure 4.3). The retrospective analysis was good with five peels converging and Mohn's rho values within the acceptable range (Figure 4.4).

Table 3.4. LPUE model inputs, parameters and diagnostic results.

Model Runs	**LPUE Run**	
	convergence (4)	
Convergence		
Input series	Catch	1991–2019
	LPUE	1995–2019
	Survey	2005–2019
Model Parameters		
intrinsic growth rate	inp4$priors$logr <- c(-0.9, 0.5, 1)	x
initial depletion level	logbkfrac <- c(log(0.5),0.35,1)	x
process noise of F	logsdf = c(log(0.5),0.1,1)	x
Shape parameter	inpinilogn <- log(2) inp$phases$logn <- -1	x
Alpha (removed)	logalpha = c(1,1,0)	x
Beta (removed)	logbeta = c(1,1,0)	x
Diagnostics		
Normaility	LPUE index	Pass
Auto-Correlation	LPUE index	Fail
Retrospectives		Pass
Mohns rho	B/B_{MSY}	0.0320
	F/F_{MSY}	0.0871
Model Checks		
variance parameters finite	all(is.finite(fit$sd)	TRUE
Realistic production curve	calc.bmsyk(fit)	0.50
Uncertainy		
B/Bmsy (order of magnitude)	calc.om(res)	1
F/Bmsy (order of magnitude)		1
Sensitivity		
Converged		Pass

Model assumptions were checked (Table 4.4) using the checklist outlined in the SPiCT guidelines (Mildenberger *et al.*, n.d.). Tests for high uncertainty indicating a lack of contrast in the input data and sensitivity of parameter estimates did not violate model assumptions. Although the addition of the LPUE data produced promising results, these data will not be explored further as this time, as additional resources are needed to construct a standardised index.

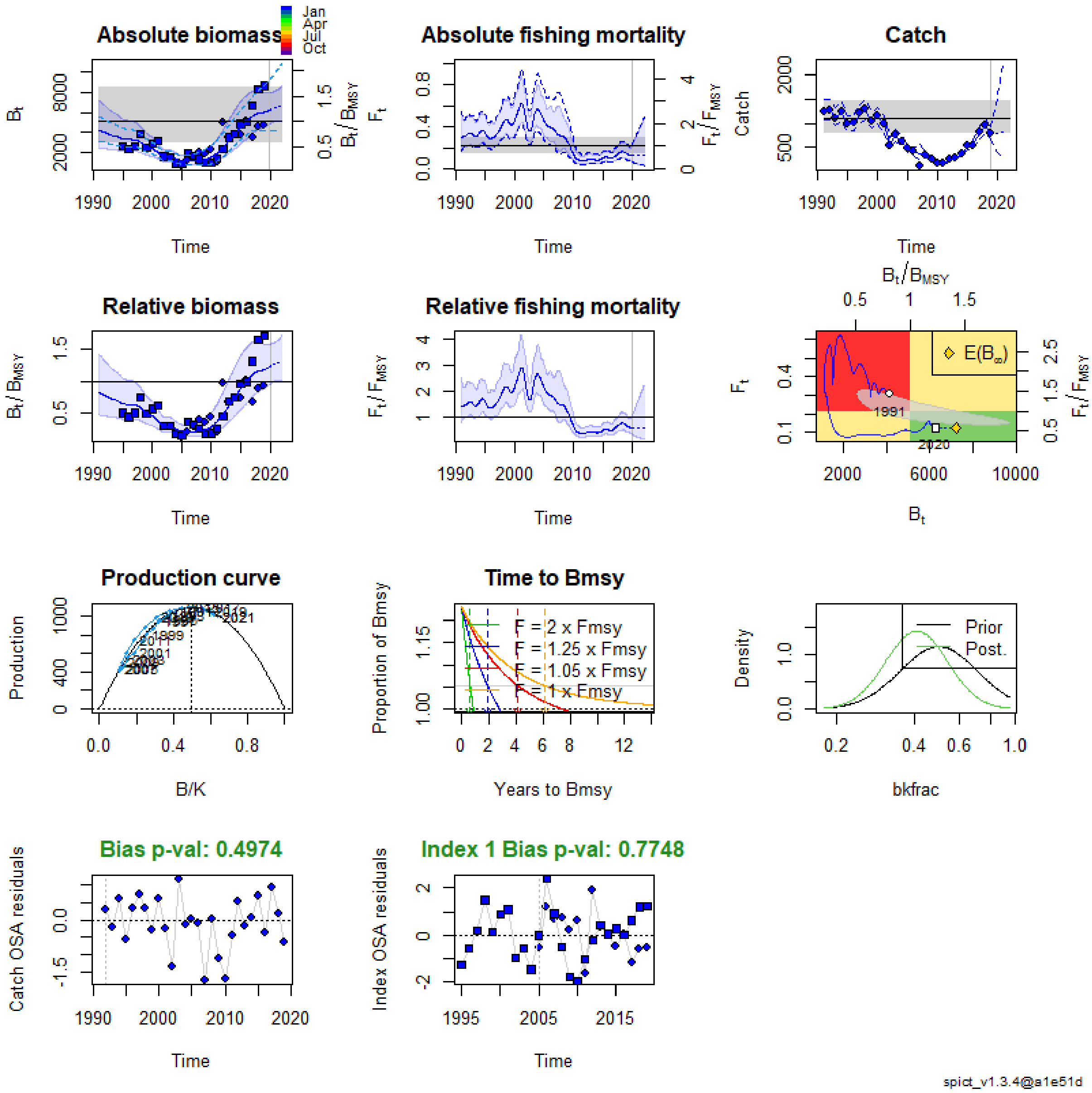

Figure 4.2. LPUE model fit.

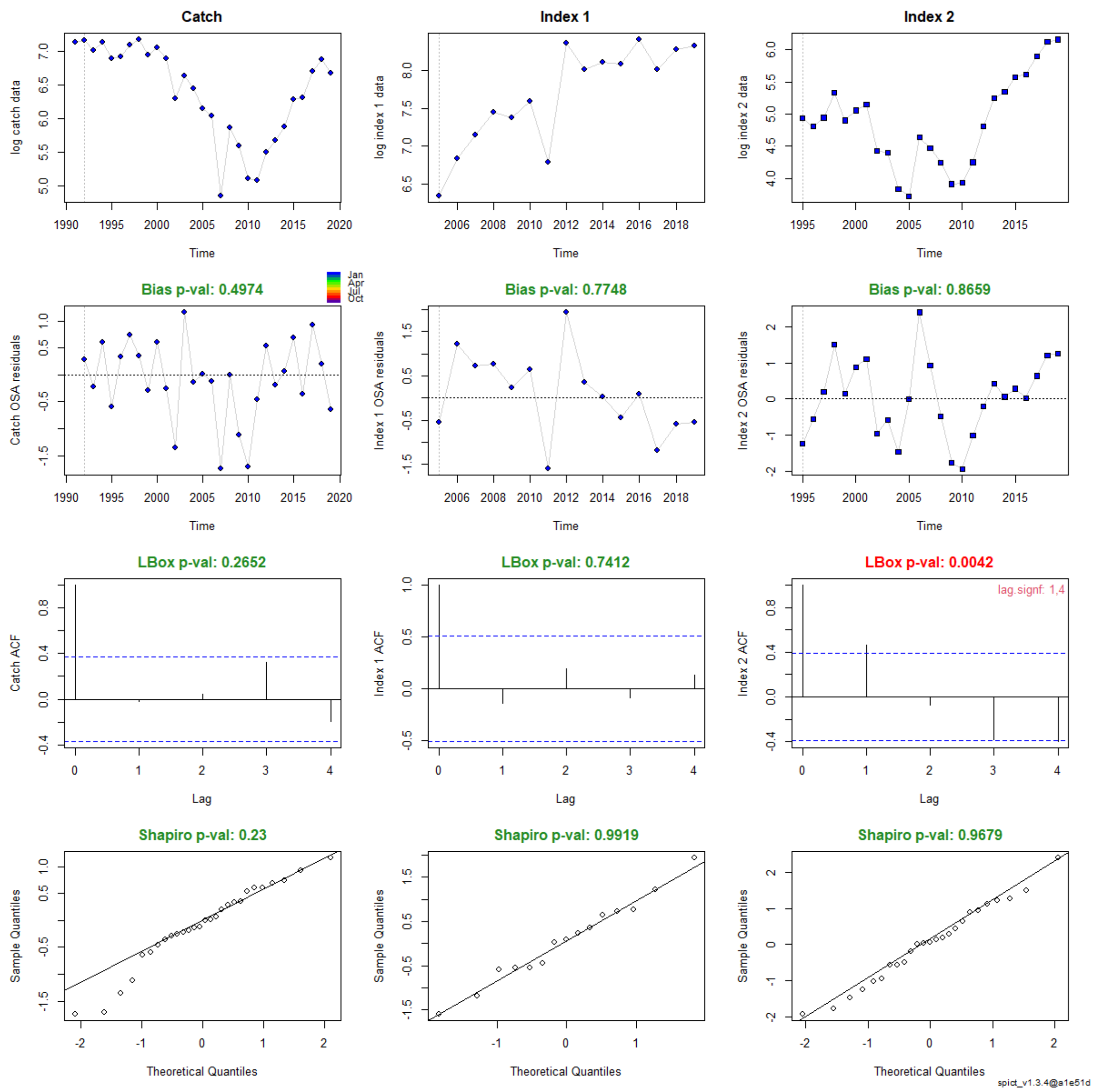

Figure 4.3. LPUE diagnostics analysis.

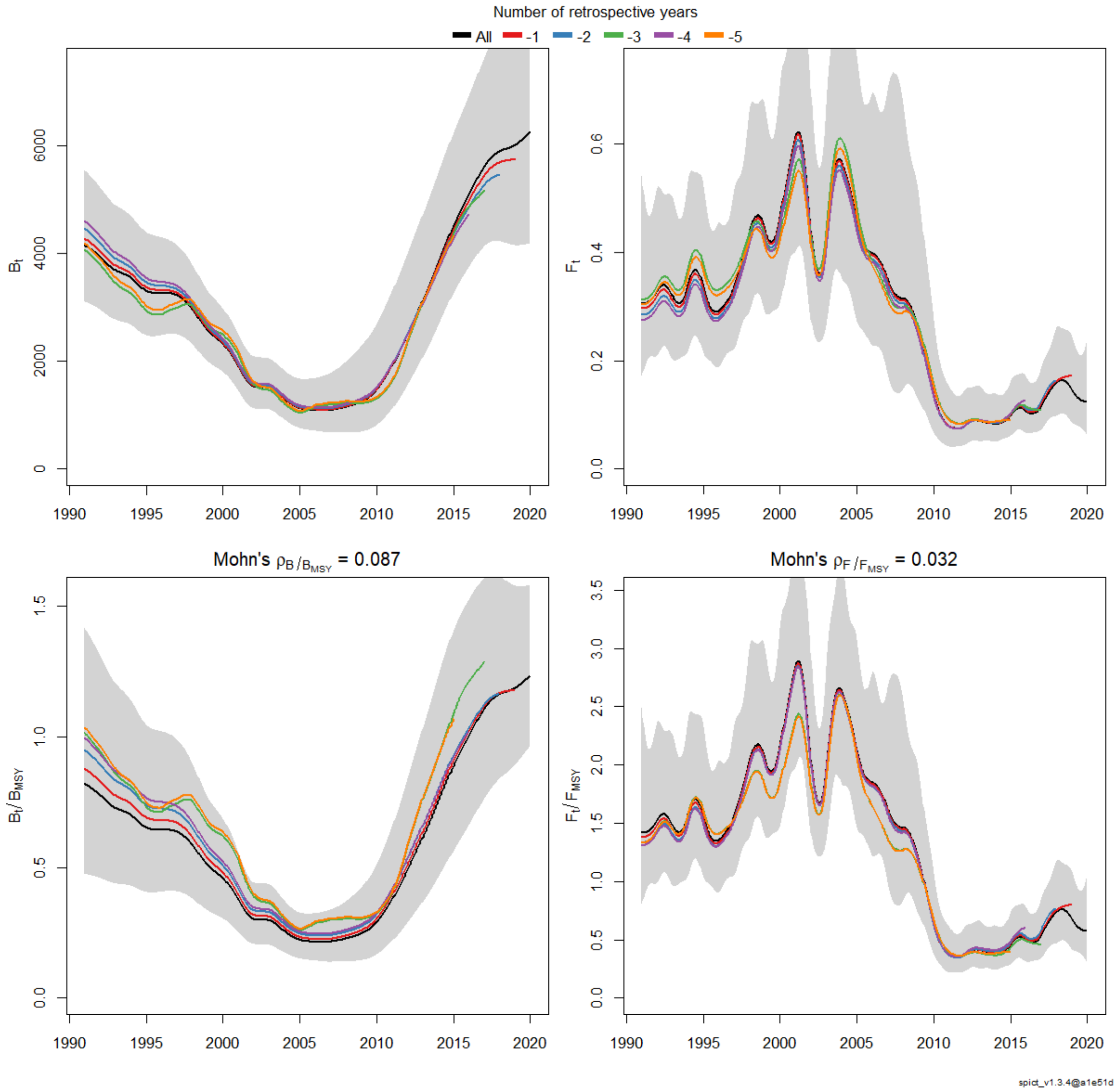

Figure 4.4. LPUE Retrospective analysis.

Overview of Model Runs at benchmark

Various parameter scenarios were explored during the benchmark; eight model configurations were tested in total. A SPiCT model was fitted to each run with convergence obtained in all; however, results varied with parameter simulations. An overview of the results is given in Table 4.7.

The input data used in model runs 1–5 coupled with parameter settings can be seen in Table 4.5. Priors were added to the intrinsic growth rate (inp$priors$logr (r)) in all 5 runs with an initial biomass depletion rate (logbkfrac) added to runs 4 and 5 only. The production curve was set to the Schaefer model (inpinilogn <- log(2), inp$phases$logn <- -1) in all cases except run 1. To mitigate the influence of possible extreme observations in the input data a robust estimation scheme (robflagc <- 1) was applied to runs 3–5.

Table 4.4. Model parameters tested on model runs 1-5.

Model Runs		Run 1	Run 2	Run 3	Run 4	Run 5
Input series		1991–2019	1991–2019	1991–2019	1991–2019	1991–2019
Model Parameters						
Intrinsic growth rate	inp$priors$logr <- c(-0.9, 0.5, 1)	x	x	x	x	x
Initial depletion level	logbkfrac <- c(log(0.5),0.5,1)				x	
	logbkfrac <- c(log(0.3),0.5,1)					x
Shape parameter	inpinilogn <- log(2)		x	x	x	x
	inp$phases$logn <- -1					
Robust estimation scheme	robflagc <- 1			x	x	x

Parameters applied to model runs 6–8 were similar to runs 1–5 with the exception of a longer catch series using the ICES historic catch statistics in runs 6 and 7, ranging from 1980–2018. Run 8 utilised the total ICES catch statistics for megrim in Subarea 6.b (Table 4.6). Full diagnostic analysis and model adequacy tests are discussed below, with results captured in Table 4.7.

Table 4.5. Model parameters tested on model runs 6–8.

Model Runs		Run 6	Run 7	Run 8
Input series		1980–2018	1980–2018	1907–2018
Model Parameters				
intrinsic growth rate	inp$priors$logr <- c(-0.9, 0.5, 1)	x	x	x
initial depletion level				
	logbkfrac <- c(log(0.6),0.5,1)	x		
	logbkfrac <- c(log(0.8),0.5,1)		x	
	logbkfrac <- c(log(0.5),0.5,1)			x
Shape parameter	inpinilogn <- log(2)	x	x	x
	inp$phases$logn <- -1			
Robust estimation scheme	robflagc <- 1	x	x	x

Results of Model Runs

Each run was analysed using SPiCT's diagnostic tools. Although all runs converged there were some diagnostic and model adequacy issues present in runs 1,2, & 5–8 (Table 4.7). Runs 1 and 2 experienced some normality and retrospective issues, with the catch data failing the Shapiro test (p-val 0.0016) in both runs. Retrospective patterns for F/F_{MSY} and B/B_{MSY} were not within acceptable ranges as only 3/5 and 4/5 peels converged in model runs 1 & 2 respectfully. There were some model sensitivity issues present also. Runs 5, 6, and 7 passed the diagnostic analysis; however, run 8 catch series failed the Shapiro test (p-val 0.0129) for normality.

Table 4.6. SPiCT diagnostics and adequacy results for all exploratory runs.

Model Runs		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Convergence		convergence (4)	convergence (4)	convergence (4)	convergence (5)	convergence (4)	convergence (4)	convergence (4)	convergence (5)
Input series		1991–2019	1991–2019	1991–2019	1991–2019	1991–2019	1980–2018	1980–2018	1907–2018
Diagnostics									
Normality	Catch	Fail	Fail	Pass	Pass	Pass	Pass	Pass	Fail
Auto-Correlation	Survey Index	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Retrospectives		Fail (3 peels)	Fail (4 peels)	Pass	Pass	Pass	Fail	Fail	Pass
Mohn’s rho	B/B_{MSY}	N\A	N\A	0.099	0.074	-0.030	0.228	0.206	0.137
	F/F_{MSY}	N\A	N\A	-0.065	-0.050	0.034	-0.193	-0.184	-0.142
Model Checks									
variance parameters finite	all(is.fi-nite(fit$sd)	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Realistic production curve	calc.bmsyk(fit)	0.507	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Uncertainty									
B/B_{MSY} (order of magnitude)	calc.om(res)	1	1	1	1	1	1	1	0
F/B_{MSY} (order of magnitude)		1	1	1	1	1	1	1	1
Sensitivity									
Converged		Fail	Fail	Yes	Yes	Fail	Pass	Pass	Fail

4.3.2 Final assessment

Run 4 displayed the best model fit and diagnostic analysis during the exploratory assessments. The benchmark recommended this run configuration be accepted as the final assessment. Official catch (Nobs C:29) together with the biomass survey index (Nobs I:15) were used as the model inputs (Figure 4.5) with the final parameter selection in Table 4.8.

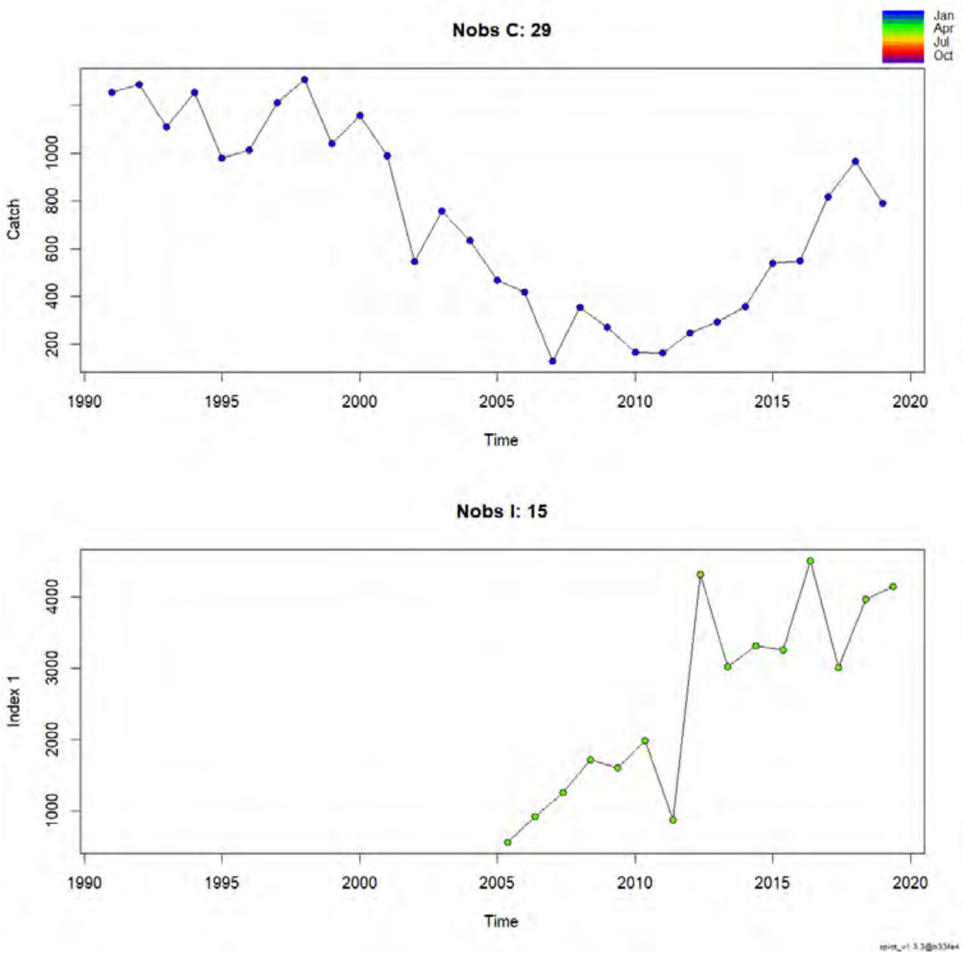

Figure 4.5. Model run 4 input data.

Table 4.7. Model 4 Parameters.

Model Runs	Run 4	
Convergence	convergence (5)	
Input series	1991–2019	
Model Parameters		
intrinsic growth rate	inp$priors$logr <- c(-0.9, 0.5, 1)	x
initial depletion level	logbkfrac <- c(log(0.5),0.5,1)	x
Shape parameter	inpinilogn <- log(2)	x
	inp$phases$logn <- -1	
Robust estimation scheme	robflagc <- 1	x

The result of fitting the above inputs and parameter setting are plotted in Figure 4.6; this multi-panel plot displays the most important outputs.

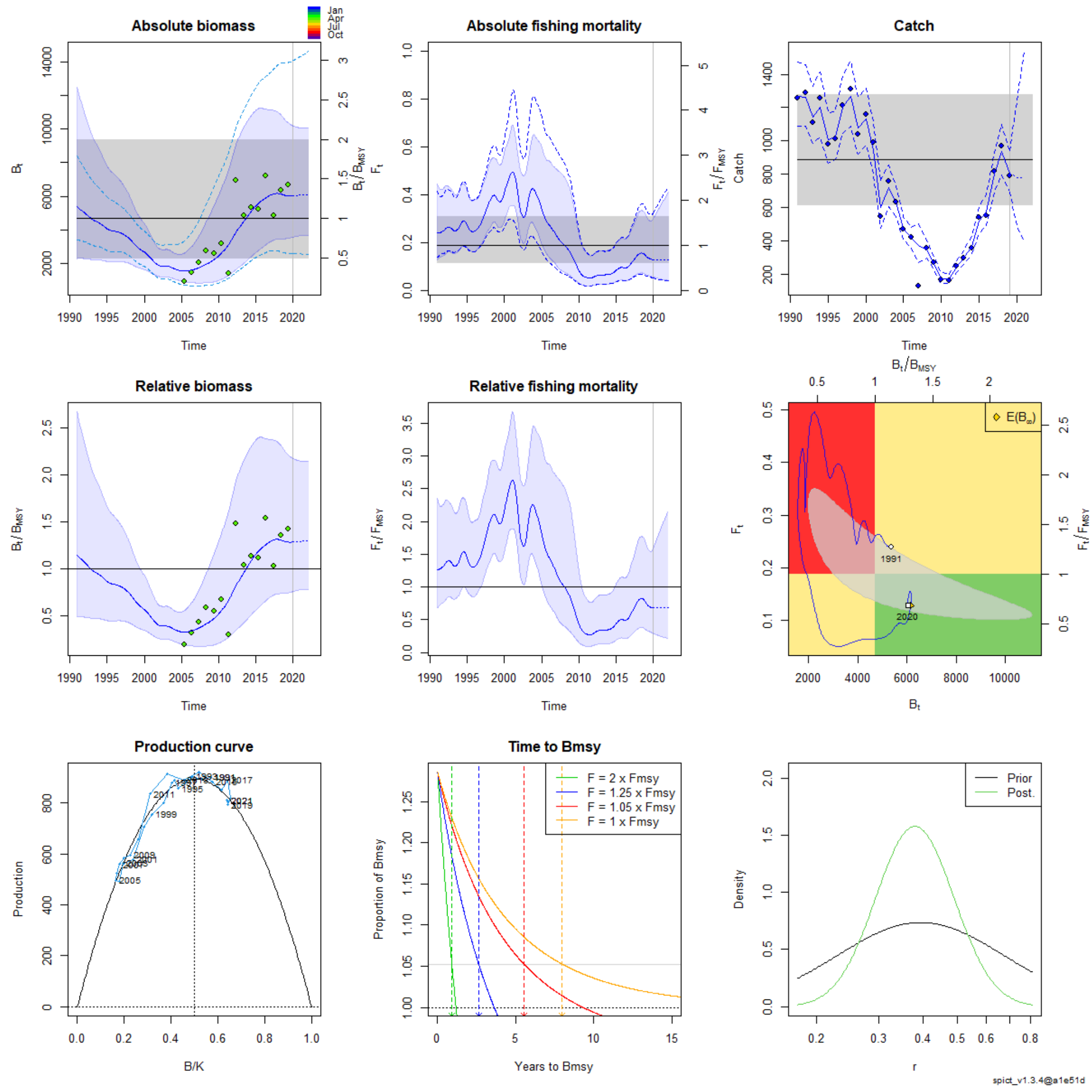

Figure 4.6. SPiCT model 4 fit summary.

The blue lines above are estimates of biomass, fishing mortality catch and production, with uncertainty intervals displayed as dashed blue lines. Model estimates of BMSY and FMSY are shown with black horizontal lines. The green points represent the absolute biomass (top left panel) and relative biomass (centre left panel) denote the SIAMISS survey, is usually completed in April of each year. Grey vertical lines denote the end of the data range with predictions beyond this point displayed as dotted blue lines. Parameter estimates are given in Table 4.9.

Table 4.8. Parameter estimates from model run 4.

Parameter	estimate	cilow	ciupp	log.est
alpha	5.7309	0.7093	46.3065	1.7459
beta	0.2814	0.0629	1.2596	-1.2681
r	0.3789	0.2308	0.6221	-0.9705
rc	0.3789	0.2308	0.6221	-0.9705
rold	0.3789	0.2308	0.6221	-0.9705
m	894.0581	616.2969	1297.0046	6.7958
K	9438.8553	4734.5392	18817.4570	9.1526
q	0.6226	0.2558	1.5156	-0.4739
sdb	0.0592	0.0076	0.4603	-2.8261
sdf	0.2843	0.1856	0.4356	-1.2576
sdi	0.3395	0.2297	0.5020	-1.0802
sdc	0.0800	0.0235	0.2718	-2.5257
pp	0.9603	0.7602	0.9946	3.1853
robfac	12.4668	2.3831	96.0666	2.4395

Diagnostics and Retrospective Analysis

The residuals were checked for violation of model assumptions. This analysis is conducted using the OSA (one step ahead) approach to assess the goodness of fit. The plots in Figure 4.7 confirms the data are normally distributed, denoted by the “Green” plot titles and p-values > 0.05 using the Shapiro and Wilks approach (Shapiro and Wilk, 1965).

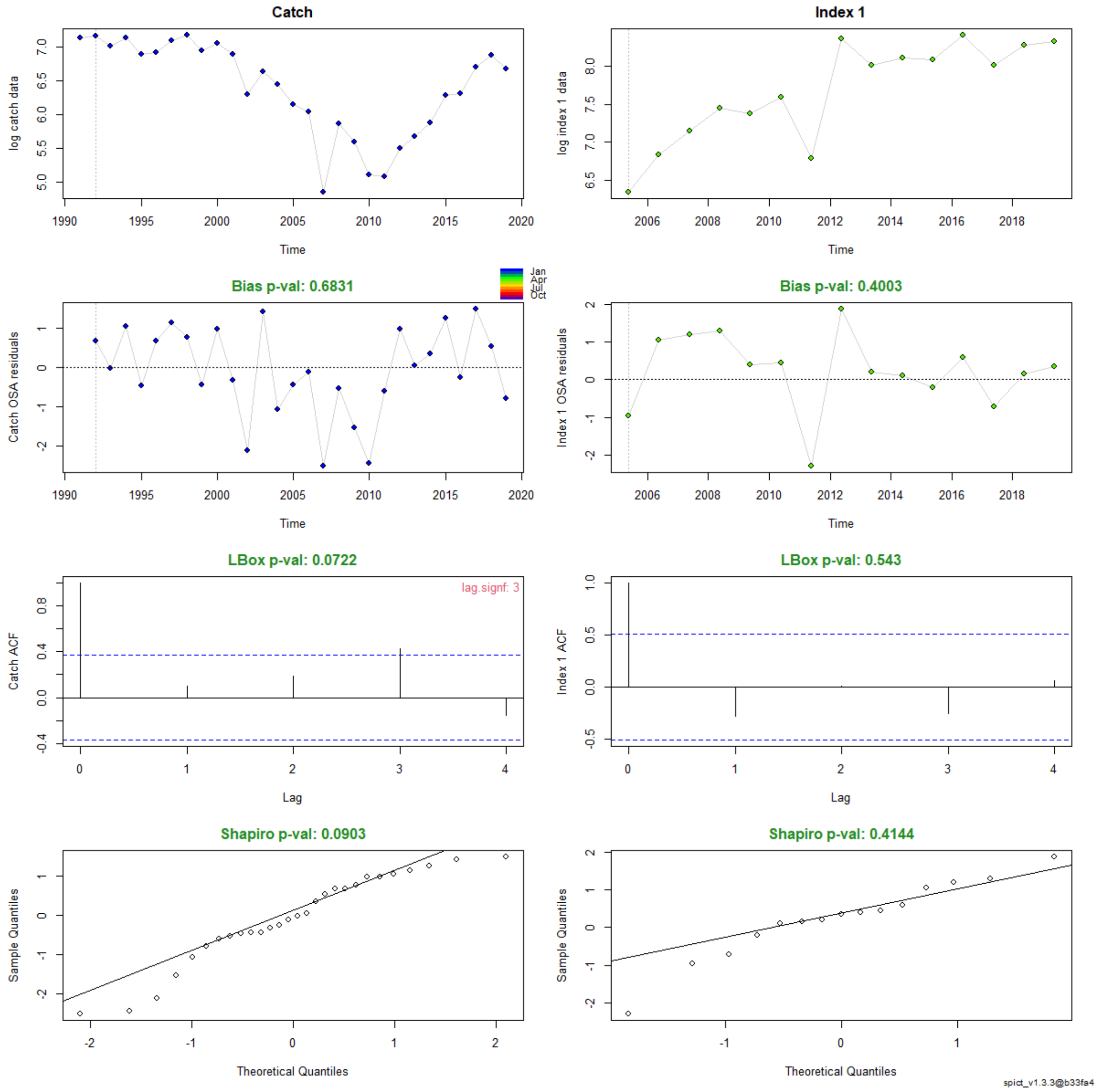

Figure 4.7. SPiCT diagnostic analysis of model 4.

Model consistency is checked through analysis of retrospective patterns, by peeling off the last five years of data in successive model runs. SPiCT evaluates the reliability of the fit by checking if substantial variation exists, as new data are added to the model. The results of this test are shown in Figure 4.8. The plot shows the various peels for the relative biomass and relative fishing mortality. For stocks where thresholds have not been clearly defined, a major retrospective pattern would be indicated by a rho value range of > 0.2 or < -0.15 outlined in WKFORBIAS for long-lived species such as megrim (ICES, 2019b). The retrospective patterns are within confidence intervals and values of Mohn's rho are within the range described earlier.

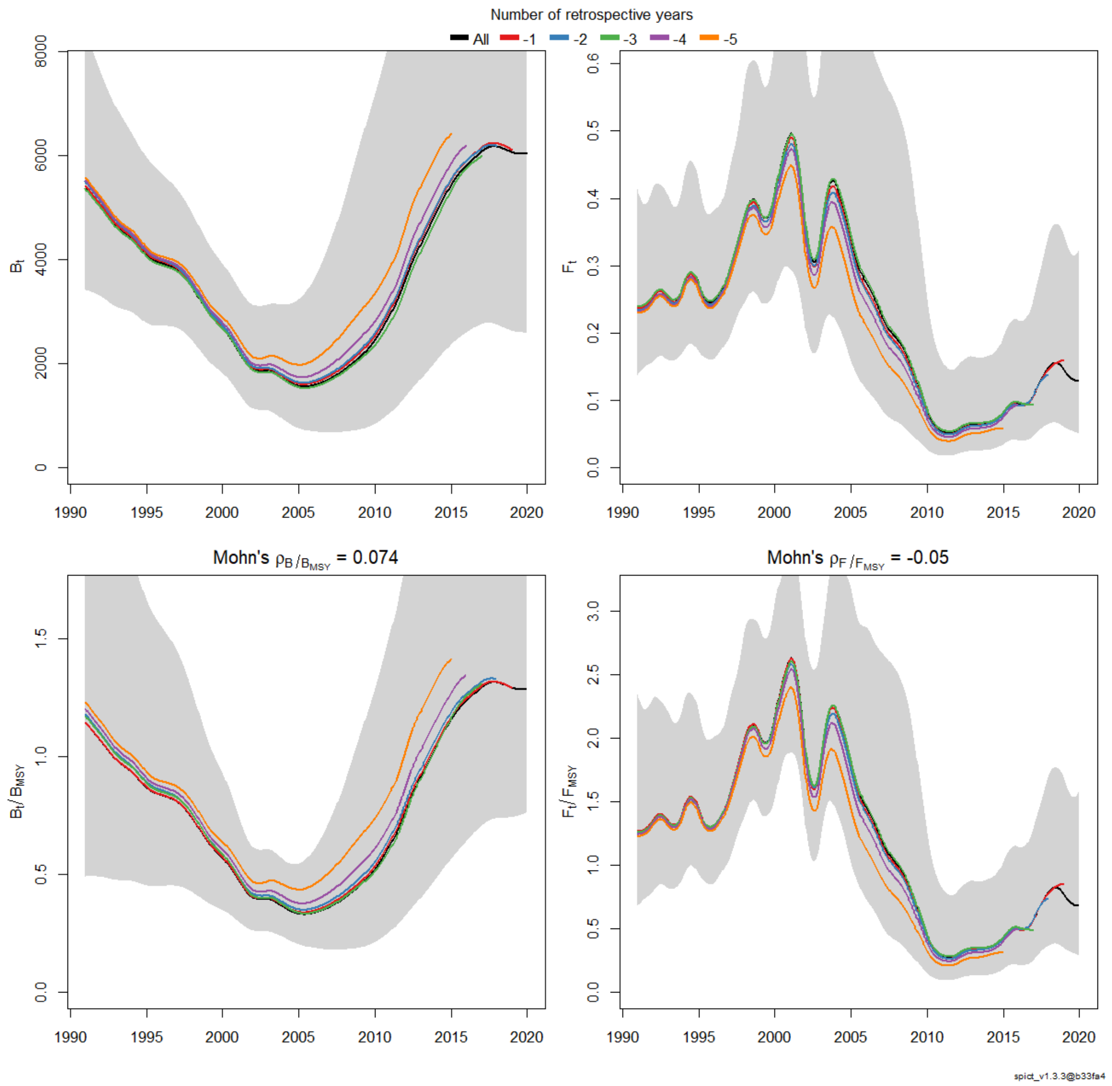

Figure 4.8. Retrospective analysis of model 4 fit.

Checks for Model Adequacy

The following characteristics were studied for model acceptance using SPiCT. The following list was taken from the guidelines set out in Mildenberger for SPiCT model (n.d.)

a) Model convergence: [1] 0, TRUE;
b) Variance parameters are finite; [1] TRUE;
c) No violations of model assumptions: [1] TRUE; Figure 4.4;
d) Retrospective patterns are consistent: [1] TRUE; Figure 4.5;
e) Production curve is realistic: [1] TRUE;
f) Assessment Uncertainty: [1] TRUE; Table 4.5;
g) Initial values do not influence the parameter estimates; estimates should be the same as for all initial values: [1] TRUE.

Run 4 Plots

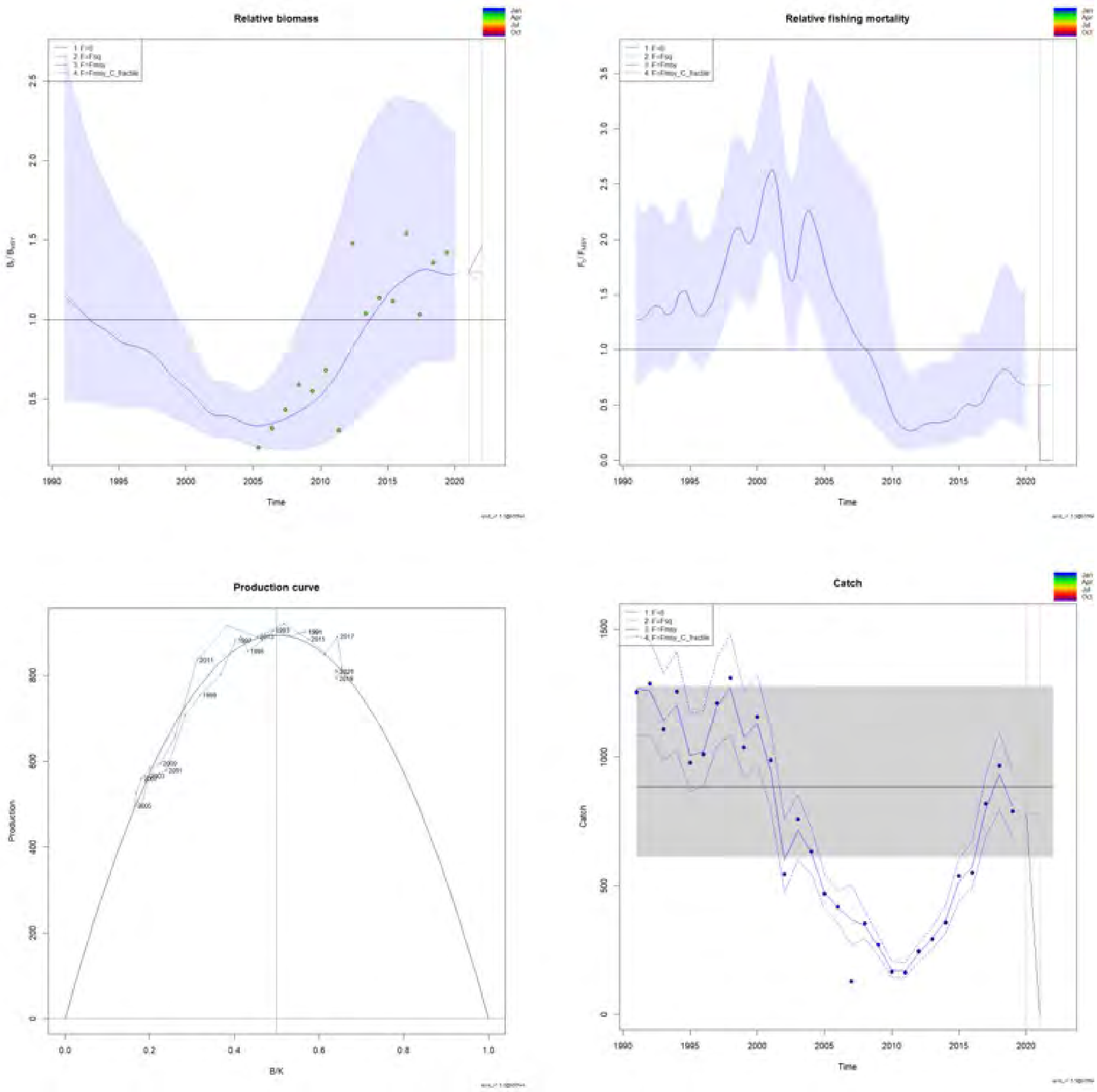

Figure 4.9. Run 4 Plots; relative biomass (top left), relative fishing pressure (top right), production curve (bottom left), and catch (bottom right).

There was no estimate of stock size in 2020 due to COVID-19 restrictions in the survey index; however, the upward trajectory of the biomass estimates since 2005, would suggest stock size in 2020 is likely above MSY $B_{trigger}$ (top left panel, black horizontal line). Fishing mortality estimate (top left panel) would suggest the stock is being exploited below F_{MSY} (Figure 4.9).

4.4 Catch forecast (ToR 4)

An updated version of SPiCT (spict_v1.3.4@a1e51d); incorporating the management options discussed and agreed during the benchmark was used. The catch forecast was run using the intermediate year option as shown in Table 4.10. The management scenarios are plotted in Figure 4.10 and Figure 4.11.

Table 4.9. Catch forecast table with management scenarios.

SPiCT timeline				
	Observations	Intermediate	Management	
	1991.00–2020.00	2020.00–2021.00	2021.00–2022.00	
Options	Description	Catch	B/B_{MSY}	F/F_{MSY}
1. F=0	No fishing	0.0	1.5	0.0
2. F=Fsq	Fishing at Status Quo	730.1	1.3	0.6
3. $F=F_{MSY}$	ICES Hockey-Stick	1123.8	1.2	1.0
4. $F=F_{MSY}$_C_fractile	35th Percentile on the Catch	1029.0	1.3	0.9
Prediction	Est	cilow	ciupp	log.est
B_2022.00	6098.11	2547.47	14597.63	8.72
F_2022.00	0.13	0.04	0.43	-2.05
B_2022.00/B_{MSY}	1.30	0.79	2.15	0.26
F_2022.00/F_{MSY}	0.68	0.21	2.17	-0.38
Catch_2021.00	781.32	397.39	1536.17	6.66
E(B_inf)	6137.08	NA	NA	8.72

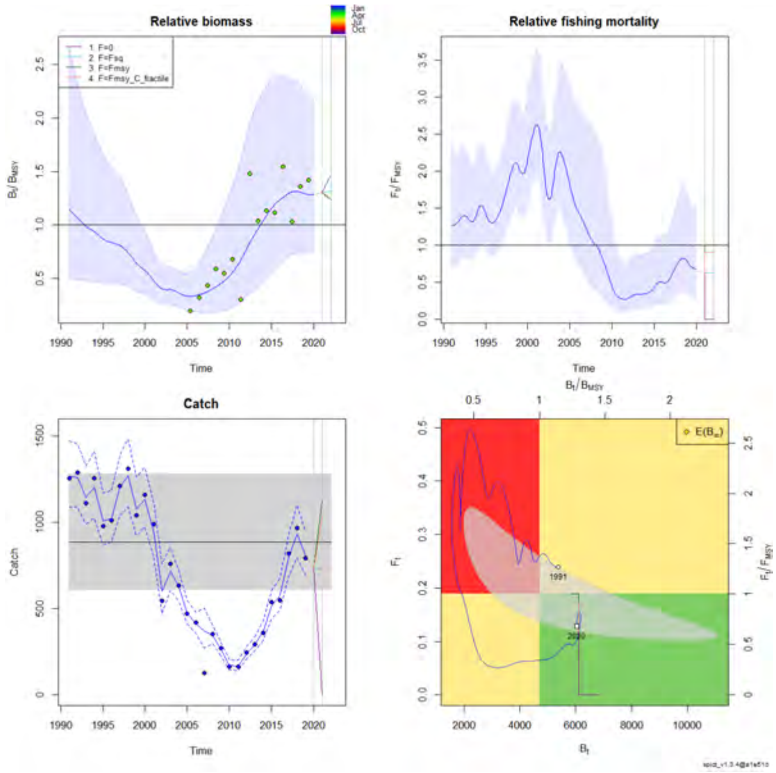

Figure 4.10. Relative biomass, fishing mortality, catch and kobe plots from forecast.

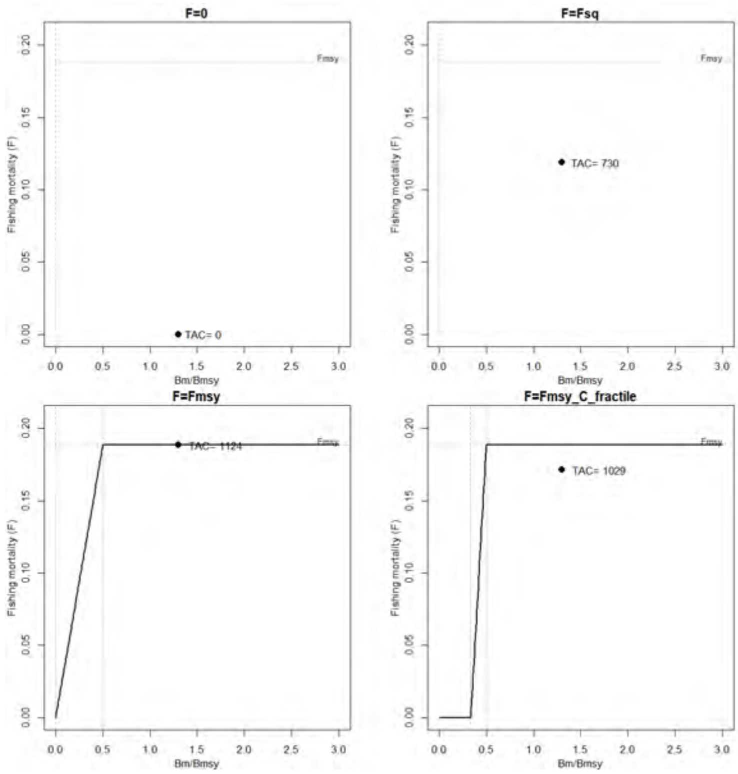

Figure 4.11. Harvest control rules for 4 management scenarios.

4.5 Future considerations/recommendations

Currently the assessment uses the SIAMISS survey to estimate biomass. It should be noted that the survey was specifically designed to catch angler fish. While this is not an issue when the biomass index is presented in the relative context, in the case of megrim; the raised biomass calculation is based on full retention of megrim in the haul. The estimates are therefore considered as the minimum.

4.6 Reviewers report

The LPUE model run provided promising results; although displaying some autocorrelation, there is enough evidence to suggest, constructing a standardised index to add further calibration of the lez6b SPiCT assessment and provide an additional source of biomass estimation.

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The stock assessment is based on a relatively short catch time-series and a single survey index. In addition, a commercial nominal (non-standardized) LPUE index was used in a sensitivity run. The results of the sensitivity run indicated no major conflicts between the survey index and the nominal LPUE, and were broadly consistent with the reference model that used only the survey index for final advice. The model fit and model diagnostics of several of the model configurations tested are satisfactory. The trends for both catches and survey are consistent with an increasing stock. However, the initial SPiCT runs predicted high biomass levels ($B > B_{MSY}$) at the start of the time-series (i.e. 1990), which would imply that limited fishing took place before 1990. From the available landings data, this assumption seems not to be supported as fisheries started likely well before 1990, considering that catches in 1990 already exceeded MSY. This is also confirmed by Figure 18 of the assessment report. To address this, residual diagnostics and retrospective analyses for additional runs with lower initial depletion priors were explored during the benchmark workshop of two additional runs using lower initial depletion priors.

Conclusions

The results of the additional model configurations confirmed the robustness of the model for advice, especially when considering that sensitivity runs that included an additional nominal LPUE index showed consistent results. Therefore, SPiCT was considered suitable for providing advice and Model 4, fitted to the survey index only and assuming a moderate initial depletion prior(logbkratio = c(log(0.5),0.5,1)) was chosen as the final model. The LPUE index could be reconsidered for inclusion in later benchmarks, provided that it has been properly standardised.

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5 Black-bellied anglerfish (*Lophius budegassa*) in divisions 8c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (ank.27.8c9a)

5.1 Introduction

The black-bellied anglerfish *Lophius budegassa*, is an important target species for the net fleets (gillnet and trammelnets) and a bycatch for the trawl fleets targeting fish or crustaceans in ICES divisions 8c and 9a. From 2018 to 2020, this stock (ank.27.8c9a) was assessed with the stochastic production model in continuous-time, SPiCT (Pedersen and Berg, 2017). The model was proposed at the Benchmark Workshop on Anglerfish Stocks in the ICES Area (WKANGLER) in 2018 and considered more reliable than the previous assessment model, ASPIC (Prager, 1994). Despite the comparable trends of the two assessment models, SPiCT was more optimistic in estimating the status of the stock: a lower ratio between the fishing mortality and F_{MSY} led to a higher catch advice under the MSY approach. The assessment performed in 2018 showed that, if fishing at F_{MSY}, catches should be increased to ~5500 tonnes, values never reached in this stock. The maximum landed weight reported for this stock was ~4000 tonnes and the biomass decreased in the following years. A stepwise procedure to achieve F_{MSY} was recommended during the WKANGLER (ICES, 2018a) and agreed at WGBIE. However, the assessment proposed by WGBIE 2018 was rejected. Given the uncertainties regarding the absolute levels of biomass and fishing pressure, the assessment was considered as indicative of trends only and it was decided to present the advice as a category 3.2 stock with proxy reference points, using SPiCT results (ICES, 2018b).

The model benchmarked in 2018 used, as input data, landings and commercial CPUEs or LPUEs for three fleets: the Portuguese trawl crustacean series, the Portuguese trawl fish series and the Spanish a Coruña trawl fleet (ICES, 2018a). Default parameters were used, only the shape of the production curve was fixed to Schaefer. Model diagnostics showed autocorrelation for index PT-TRF9a which was considered not meaningful. This auto-correlated residual pattern may reflect spatio-temporal changes in the distribution or may indicate transitory changes in catchability (ICES, 2018a). More information about the model can be found in ICES (2018a; 2018b).

5.2 Input data for stock assessment (ToR 1 & 2)

Data on biology, fisheries, landings composition, commercial CPUEs and research survey data were compiled and presented in the data evaluation workshop and updated at the benchmark workshop (Moura and Sampedro, 2020 WD; Moura, 2020 WD; Moura, 2021 WD). Data is also described in ICES (2018a), ICES (2020a) and in the stock annex. For the purpose of this report, only new data or data of interest for the proposed assessment model will be presented.

5.2.1 Commercial fisheries

5.2.1.1 Landings

Landings are reported by ICES division and métier by Spain (since 1978), Portugal (since 1978) and France (since 2002). Portuguese landings were TAC constrained from 2005 to 2011 and low landings were registered in the 4th quarters during that time period. Since 2010 that Portuguese landings in the 1st quarter are lower given the prohibition to land *Lophius* species in January and February (to protect these species during the reproductive season). Landings by division and fleet are presented in Table 5.1 and Figure 5.1. Landings for this stock derive, in a great extent, from trawl fleets operating in ICES divisions 8c and 9a and from the Portuguese artisanal fleet (mainly trammelnets) operating in ICES Division 9a (Figure 5.2). Gillnet fisheries in 8c also contribute to a great fraction of the catches. Spanish catches in southern 9a (Gulf of Cadiz) are from trawlers and, in the last three years, represented between 3 and 5% of total catches of the stock.

Table 5.1. *Lophius budegassa* in ICES divisions 8c and 9a. Tonnes landed by the main fishing fleets for 1978–2019 as determined by the Working Group. Adapted from ICES (2020b).

	Div. 8c							Div. 9a						Div. 8c+9a		
	SPAIN			FRANCE				SPAIN			PORTUGAL				Unalloca ted/Non reported	
Year	Trawl	Gillnet	Others	Trawl	Gillnet	Others	TOTAL	Trawl	Gillnet	Others	Trawl	Artisanal	TOTAL	SUBTOTAL		TOTAL
1978	n/a	n/a					n/a	248			n/a	107	355	355		355
1979	n/a	n/a					n/a	306			n/a	210	516	516		516
1980	1203	207					1409	385			n/a	315	700	2110		2110
1981	1159	309					1468	505			n/a	327	832	2300		2300
1982	827	413					1240	841			n/a	288	1129	2369		2369
1983	1064	188					1252	699			n/a	428	1127	2379		2379
1984	514	176					690	558			223	458	1239	1929		1929
1985	366	123					489	437			254	653	1344	1833		1833
1986	553	585					1138	379			200	847	1425	2563		2563
1987	1094	888					1982	813			232	804	1849	3832		3832
1988	1058	1010					2068	684			188	760	1632	3700		3700
1989	648	351					999	764			272	542	1579	2578		2578
1990	491	142					633	689			387	625	1701	2334		2334
1991	503	76					579	559			309	716	1584	2162		2162
1992	451	57					508	485			287	832	1603	2111		2111
1993	516	292					809	627			196	596	1418	2227		2227
1994	542	201					743	475			79	283	837	1580		1580
1995	924	104					1029	615			68	131	814	1843		1843
1996	840	105					945	342			133	210	684	1629		1629
1997	800	198					998	524			81	210	815	1813		1813
1998	748	148					896	681			181	332	1194	2089		2089
1999	565	127					692	671			110	406	1187	1879		1879
2000	441	73					514	377			142	336	855	1369		1369
2001	383	69					452	190			101	269	560	1013		1013
2002	202	74		10	1	0	288	234	0	0	75	213	522	810		810
2003	279	49		9	0	0	338	305	0	0	68	224	597	934		934
2004	251	120		14	5	0	391	285	0	0	50	267	603	993		993
2005	273	97		26	9	0	405	283	0	0	31	214	527	933		933
2006	323	124		12	1	0	460	541	0	0	39	121	701	1161		1161
2007	372	68		4	1	0	444	684	0	0	66	111	861	1306		1306
2008	386	70		5	1	0	462	336	0	0	40	119	495	957		957
2009	301	148		3	1	0	454	172	0	0	34	114	320	774		774
2010	319	81		2	1	0	403	197	0	0	70	84	351	754		754
2011	214	115	32	3	0	0	364	157	60	98	75	119	510	874	74	948
2012	161	83	22	2	0	0	268	109	40	90	156	370	765	1033	109	1141
2013	221	135	14	4	1	0	375	95	55	90	100	258	598	973	98	1071
2014	187	126	7	5	2	0	326	120	47	4	116	286	572	898	100	998
2015	233	141	1	2	2	0	380	103	62	2	126	222	515	895	152	1047
2016	203	118	5	2	2	0	330	103	79	2	120	257	560	889	125	1014
2017	163	153	0	1	3	0	319	109	62	1	68	302	542	861		861
2018	186	156	1	7	9	0	359	126	37	1	52	185	402	761	11	773
2019	137	117	0	1	2	0	259	109	49	1	43	135	337	595	73	669

n/a: not available

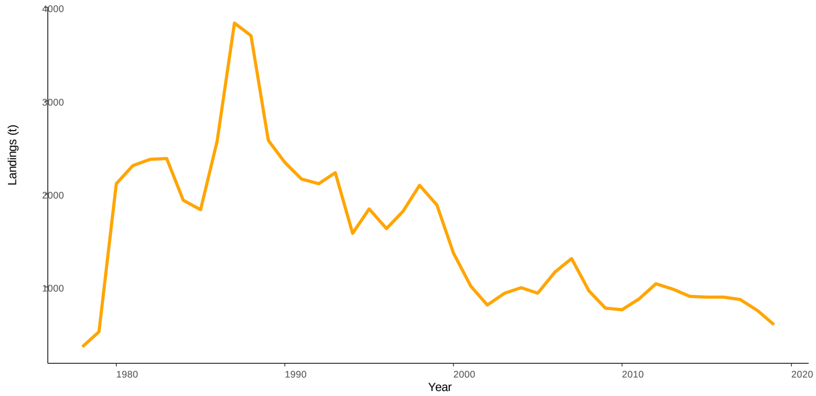

Figure 5.1. *Lophius budegassa* in ICES divisions 8c and 9a. Estimated landings (1978–2019).

Figure 5.2. *Lophius budegassa* in ICES divisions 8c and 9a. Proportion of total landings of each fleet, by ICES division (1980–2019).

This species is usually landed with the white anglerfish and misidentification at landings ports is known to occur. Therefore, estimates of each species in Spanish landings from divisions 8c and 9a, and Portuguese landings of Division 9a are derived from their relative proportions in market samples. There is a latitudinal gradient observed in the proportion of these species, with *L. budegassa* proportions increasing remarkably in landings from the northern to the southern landing ports.

There is a series of unreported landings for the period 2011–2019 allocated to Spain, which represents from 1 to 15% of total landings. The unreported landings are considered realistic and are included in the stock assessment.

5.2.1.2 Historical landings

Table 5.2 and Figure 5.3 present ICES historical landings, by country, for *L. budegassa, L. piscatorius*, *Lophius* spp. and Lophiidae combined (due to misidentification issues in landings statistics) in ICES divisions 8c and 9a from 1911 to 1980. Values suggest misreporting (e.g. the same values are reported for Portugal and Spain for several years) and therefore were considered not adequate to be used in the assessment.

In this area, the commercial interest for both *Lophius* started in the late 1970s (Duarte, 2002), and gained a special interest in the 1980´s with the development of target fisheries due to its acceptance in the market trade (Azevedo, 1996). Previous to this period, *L. budegassa* were likely caught as bycatch from trawl and net fisheries but discarded.

Table 5.2. Historical landings data of *L. budegassa*, *L. piscatorius*, *Lophius* spp. and Lophiidae (combined) in ICES divisions 8c and 9a, by country (ICES database).

Year	Belgium	France	Germany	Ireland	Portugal	Spain	UK England & Wales	Total
1911			3				3520	3523
1912							3288	3288
1913			1				5477	5478
1914							1253	1253
1915							2157	2157
1919							1	1
1920							3519	3519
1921							6791	6791
1922							3288	3288
1923							4922	4922
1924							575	575
1925			1				5877	5878
1926							24	24
1927					441		24	465
1928	1	1			4515		1	4518
1929	3519				4421		24	7964
1930	2157				6396		1	8554
1931	3519				3407		24	6950
1932					2903		24	2927
1933					1039			1039
1934					1253			1253
1935					2758			2758
1936					2157			2157
1937					4155			4155
1938		1			1443			1444
1942					4514			4514
1943					2157			2157
1944					2157			2157
1945					2157			2157
1946					24			24
1947					7489	3128		10617
1948					7489	2917		10406
1949						2263		2263
1950		4		2	22480	22257		44743
1951		4		2	29968	21177		51151
1952		4		2	22480	17889		40375
1953		4		2	22480	18840		41326
1954		4		2	22480	18943		41429

Year	Belgium	France	Germany	Ireland	Portugal	Spain	UK England & Wales	Total
1955		4		2	22480	14988		37474
1956		4		2	22480	14988		37474
1957		4		2	22480	14988		37474
1958		4		2	22480	14988		37474
1959		4		2	26992	18086		45084
1960		4		2	28960	19565		48531
1961		4		2	28873	15324		44203
1962		4		2	28355	16697		45058
1963		4		2	22787	16302		39095
1964		4		2	22502	14988		37496
1965		4		2	26722	14988		41716
1966		4		2	22502	14988		37496
1967		4		2	20296	14988		35290
1968		4		2	29969	14988		44963
1969		4		2	22503	14988		37497
1970		4		2	29969	14988		44963
1971		4		2	22502	14988		37496
1972		4		2	22502	14988		37496
1973		4		2	37456	14988		52450
1974		4		2	37456	14988		52450
1975		4		2	37456	14988		52450
1976		4		2	37456	14988		52450
1977		7515		2	37456	14988		59961
1978		7493		2	37456	14988		59939
1979		2159		2	37456	14988		54605
1980		4		2	37456	14988		52450

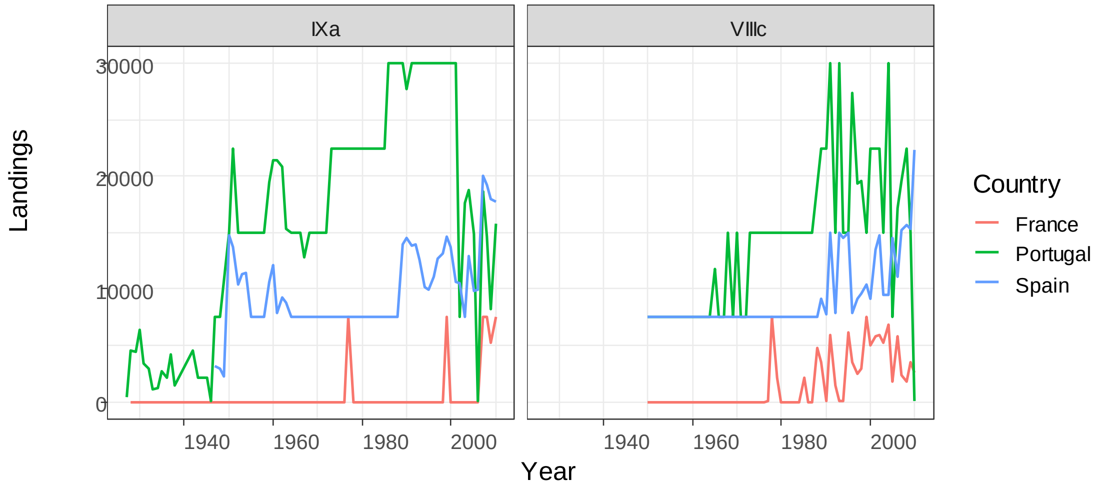

Figure 5.3. Historical landings data of *L. budegassa*, *L. piscatorius*, *Lophius* spp. and Lophiidae (combined) by ICES division (8c and 9a) and by country (Portugal, Spain and France) (ICES database).

5.2.1.3 Discards

Discards are considered negligible for Portuguese fleets and low for Spanish fleets and are not included in the assessment of this stock. Spain provides an annual estimate of discards in weight for trawl since 1994 (with gaps for years 1995, 1996, 1998, 2001 and 2002) and for gillnet fleets since 2013. With exception of 2006 and 2010, discards for the trawl and gillnet fleets represent low proportions of the total catches in each year (<3%, mostly <1%).

5.2.2 CPUE and LPUE indices

The model benchmarked in 2018 uses, as input data, the following three commercial indices: Portuguese trawlers targeting crustaceans in Division 9a (PT-TRC9a), Portuguese trawlers targeting fish in Division 9a (PT-TRF9a) and Coruña Trawl Fleet in Division 8c (SP-CORTR8c). The Portuguese trawlers series were standardized for WKMSYSPiCT. A new commercial CPUE index for the Portuguese trammelnet fishery targeting anglerfish in 9a (PT-GTR) was made available as well as the new index for the Coruña Trawl Fleet in Division 8c (SP-CORTR8c). The description of these commercial CPUE series as well, as the methodologies for CPUE standardization are presented below.

Portuguese trawlers targeting crustaceans in Division 9a (PT-TRC9a)

CPUE data are available from the Portuguese trawlers targeting crustaceans since 1989. This fishery operates in the southwest and south coasts and represents an average of 3% of international catches of black anglerfish along the time-series. CPUE consists on the biomass caught (in kg) by hour and is estimated from logbook data. A standardized CPUE series from 1989–2008 was made available for WGHMM. Comparison between standardized and non-standardized CPUEs showed no major differences between series and the non-standardized series has been used in the black anglerfish assessment (Cardador *et al.*, 2008; Cardador, 2009). A revision and standardization of this CPUE series was again conducted for WKMSYSPiCT and is described at the end of this section.

Portuguese trawlers targeting fish in Division 9a (PT-TRF9a)

CPUE data are available from the Portuguese trawlers targeting fish since 1989. This fishery operates in the occidental coast and represents an average of 5% of international catches of black anglerfish along the time-series. CPUE consists on the biomass caught (in kg) by hour and is estimated from logbook data. A standardized CPUE series from 1989–2007 was made available for WGHMM. Comparison between standardized and non-standardized CPUEs showed no major differences between series and the non-standardized series has been used in the black anglerfish assessment (Cardador *et al.*, 2008; Cardador, 2009). A revision and standardization of this CPUE series was again conducted for WKMSYSPiCT and is described at the end of this section.

Coruña Trawl Fleet in Division 8c (SP-CORTR8c) – Fleet and Port series

The LPUE series for the A Coruña trawl fleet (kg/day * 100 horse power) in Division 8c is available for the years 1982–2012 (Figure 5.4 and Table 5.3). This is a mixed-fishery targeting various demersal (hake, megrims, anglerfish) and pelagic species (mackerel, horse mackerel) which represents an average of 18% of international catches of black anglerfish along the available time-series. A standardized LPUE series from 1994–2006 is also available for this fleet with annual effort data (in fishing days). Comparison between standardized and non-standardized LPUE showed no major differences between series and the non-standardized series has been used in the black anglerfish assessment (Cardador *et al.*, 2008).

The change in the source of the information and the methodology used to estimate the LPUE prevented the use of the series since 2012. The new information that has been reported since 2013 for the SP-CORTR8c currently constitutes a 7-year series (Table 5.3 and Figure 5.4). The main difference between the methods used to estimate both LPUEs is related with the quantification of the effort. Until 2012, the duration of the fishing trips was a fix value of 1.5 or two days depending on the target species. Since 2013, the logbook's information was used to estimate the exact duration of each trip, being the effort more precisely estimated. Also, the new series of LPUE - SP-CORTR8c (port series) is calculated using only the information from vessels whose official base port is A Coruña. Previously, all vessels operating regularly in A Coruña were included in the calculations - SP-CORTR8c (fleet series).

Table 5.3. LPUE for the A Coruña Trawl Fleet in Division 8c (SP-CORTR8c): fleet (1982–2012) and port series (2013–2019).

	Fleet	Port
1982	10.3	
1983	15.0	
1984	11.8	
1985	5.6	
1986	8.7	
1987	19.4	
1988	13.7	
1989	7.7	
1990	6.5	
1991	5.6	
1992	5.4	
1993	4.5	
1994	3.9	
1995	8.3	
1996	9.0	
1997	7.7	
1998	10.9	
1999	12.4	
2000	9.6	
2001	9.4	
2002	3.7	
2003	4.9	
2004	3.6	
2005	2.8	
2006	4.7	
2007	6.4	
2008	8.7	
2009	5.1	
2010	8.7	
2011	7.7	
2012	8.2	
2013		6.0
2014		4.4
2015		5.0
2016		6.5
2017		5.2
2018		6.0

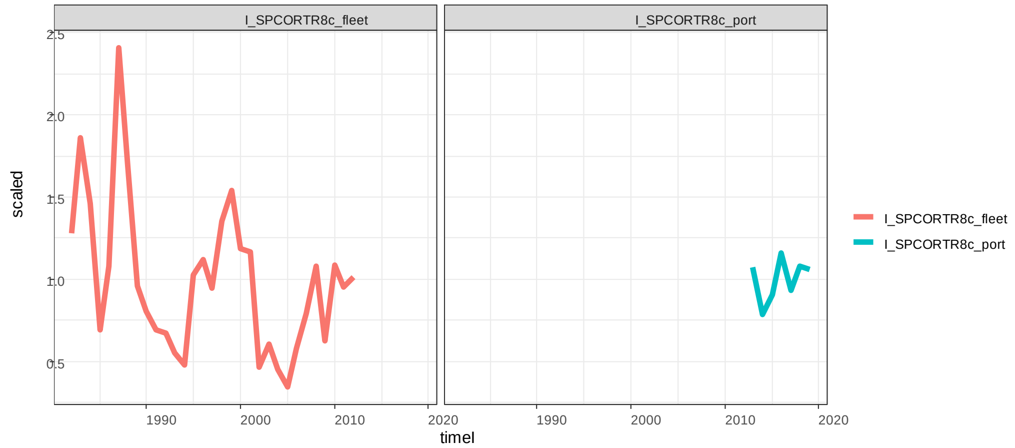

Figure 5.4. *Lophius budegassa* in ICES divisions 8c and 9a. Commercial LPUE for the for the Coruña Trawl Fleet in Division 8c (SP-CORTR8c): A – fleet series, used in the assessment (1982–2012); B – port series (2013–2019).

Portuguese artisanal fleet in Division 9a

Portuguese landings of black anglerfish are mainly attributed to the artisanal fleet. This fleet represents, in average, 22% of the total catches of the stock. Within this fleet, vessels targeting both *Lophius* species with trammelnets represent 75–90% of the catches. A standardized CPUE series using logbook data has been developed with data from 2008 to 2019 but improvements are needed. The series was considered not adequate for stock assessment. Standardization procedure is described in Section 5.2.1.5.

5.2.2.1 Standardization procedure of Portuguese trawl fleets

A standardization procedure was implemented for both Portuguese trawl fleets based on logbook data (1989–2019). Logbook reports have theoretically more precise information on landings, with catches being reported by day of catch, ICES rectangles (or geographical coordinates in case of electronic logbooks), and fishing gear. Data used for assessment were revised and some issues were detected with input data for the years 2012 and 2013 (a considerable fraction of logbook data were missing from the dataset), which were corrected.

For each logbook record with anglerfish (*Lophius* spp.), catches by species were estimated based on species proportions by year and area (north, southwest and south). Hauls with reported catches of *L. budegassa* were selected for analysis. In the case of the PT-TRC9a, that operates in the centre and south, occasional hauls reported for the northern area were excluded. In the case of the PT-TRF9a fleet, since both catches are very low in the northern area (Figure 1), the northern area was also excluded from the analysis.

A generalized linear mixed model (GLMM) was used to standardize both CPUE data. The following model was fitted to the response variable CPUE (landings of anglerfish by haul):

GLMM: (log(ANK) ~ Year + Quarter + Area, random=Vessel)

considering as independent variables: Year, Quarter and Area (centre and south). The vessel identity (Vessel) was considered as the random variable, due to the high number of levels and relatively little data on most levels.

All the independent variables were modelled as categorical variables. Modelling was conducted in R software, using package “glmmTMB” (Brooks *et al*., 2017). CPUE data were log transformed and modelled assuming the normal probability distribution. Model´s adequacy was checked based on residual analysis. Estimated marginal means for the variable year were extracted using package “emmeans” (Lenth, 2020).

In the case of the crustacean fleet, data were considered insufficient to be included in the analysis for the years 1989, 1991 and 2002. Table 5.4 and Figure 5.5 show results obtained for each fleet. Residuals suggest a good fit to the data (Figure 5.6). The standardized CPUE indices are similar to the non-standardized CPUEs except for the PT-TRF9a, for which the input data differed from the data used in the non-standardized series (Figure 5.7). Standardized CPUEs was used in the exploratory assessments with SPiCT.

Table 5.4. Standardized CPUE index (kg.haul^{-1}) for the Portuguese trawl fleets from 1989 to 2019 and respective standard error (±1 se).

Year	PT-TRC9a		PT-TRF9a		PT-TR9a
	CPUE	se	CPUE	se	(combined)
1989			3.18	0.34	
1990	0.78	0.31	5.26	0.42	1.26
1991			3.68	0.30	
1992	0.94	0.17	2.44	0.19	0.75
1993	0.84	0.08	2.35	0.19	0.70
1994	0.57	0.05	1.24	0.11	0.41
1995	0.63	0.06	1.55	0.16	0.49
1996	0.68	0.06	2.26	0.19	0.64
1997	0.87	0.06	1.35	0.14	0.52
1998	1.23	0.09	1.20	0.09	0.59
1999	0.85	0.12	1.58	0.12	0.56
2000	2.46	0.29	2.03	0.18	1.11
2001	0.77	0.06	1.01	0.28	0.42
2002			2.95	0.41	
2003	0.67	0.04	2.42	0.20	0.67
2004	0.88	0.06	1.97	0.19	0.64
2005	0.68	0.04	1.25	0.13	0.44
2006	0.96	0.06	1.46	0.11	0.56
2007	1.31	0.08	2.71	0.20	0.91
2008	1.19	0.08	2.14	0.17	0.77
2009	0.95	0.06	1.84	0.16	0.64
2010	1.51	0.09	2.86	0.22	1.00
2011	2.23	0.13	2.79	0.20	1.20
2012	2.40	0.13	5.35	0.35	1.75
2013	2.30	0.13	3.85	0.25	1.42
2014	2.74	0.15	3.22	0.21	1.43
2015	3.28	0.19	2.84	0.18	1.51
2016	4.49	0.26	4.10	0.26	2.11
2017	3.72	0.21	2.66	0.18	1.60
2018	4.64	0.27	2.87	0.20	1.92
2019	3.52	0.20	2.72	0.19	1.56

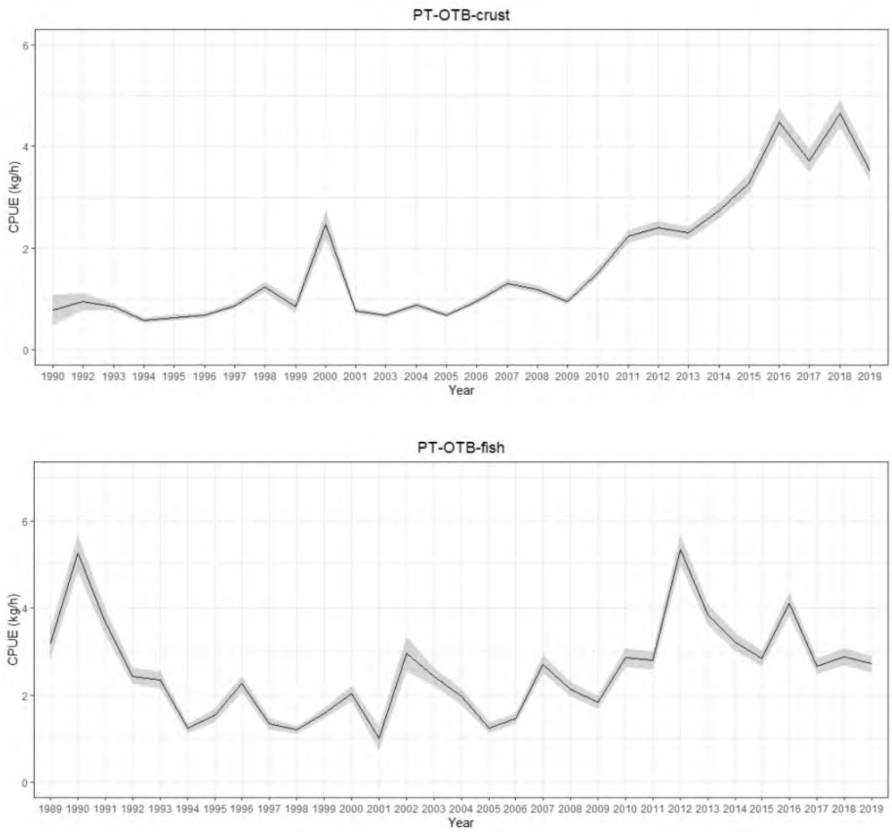

Figure 5.5. Standardized CPUE index (kg.haul^{-1}) for the Portuguese trawl fleets from 1989 to 2019 and respective standard error (±1 se). Top: Portuguese trawl fleet targeting crustaceans (PT-OTB-crust: PT-TRC9a); bottom: Portuguese trawl fleet targeting fishes (PT-OTB-fish: PT-TRF9a).

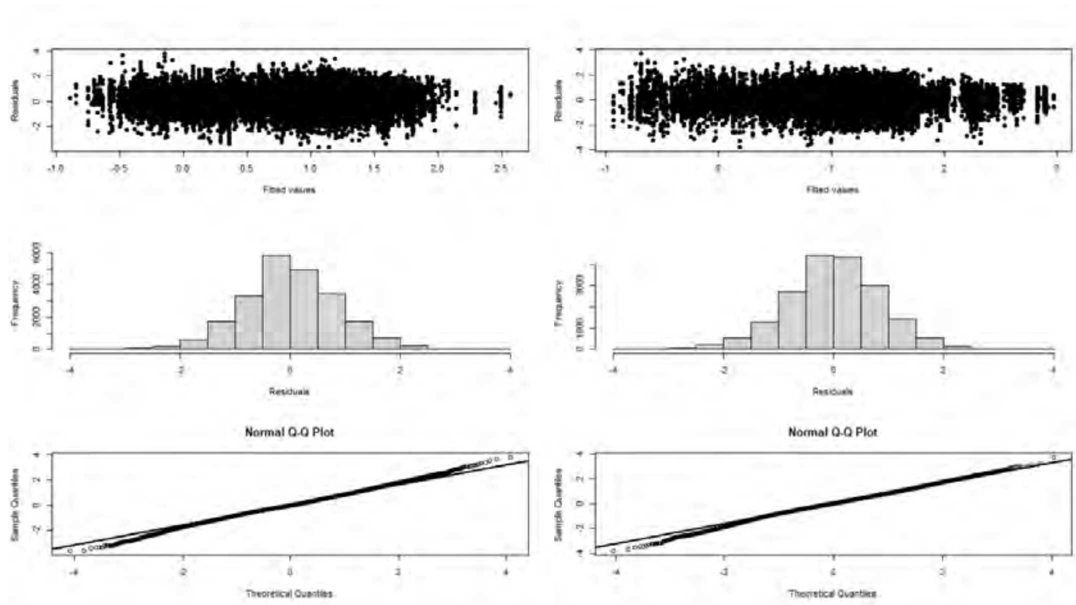

Figure 5.6. Model residuals for PT-TRC9a (left) and PT-TRF9a (right). Top: fitted vs residuals; middle: residuals distribution plot; bottom: Q-Q plot.

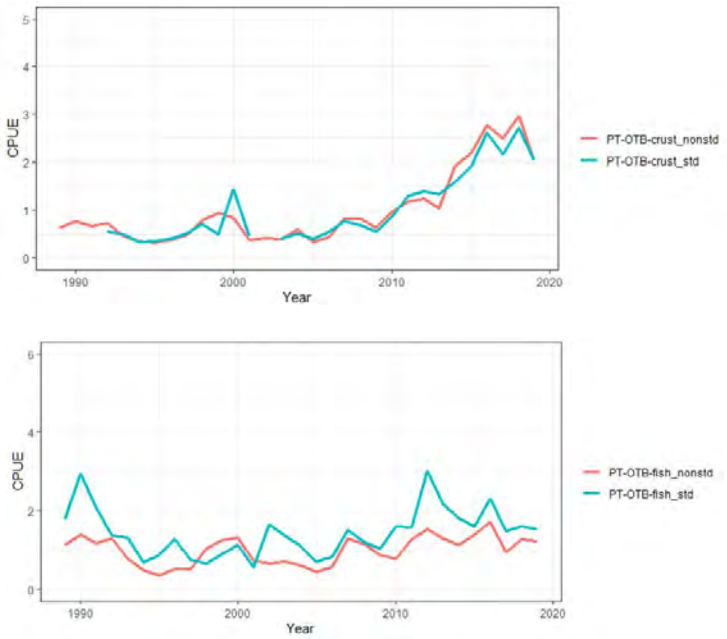

Figure 5.7. Trend comparison of the standardized CPUE index (kg.h^{-1}) and the non-standardized CPUE currently used in the assessment of ank.27.8c9a (both scaled to the mean). Top: Portuguese trawl fleet targeting crustaceans (PT-OTB-crust: PT-TRC9a); bottom: Portuguese trawl fleet targeting fishes (PT-OTB-fish: PT-TRF9a).

5.2.2.2 Standardization procedure of Portuguese trammel net fleet

A standardization procedure was implemented for the trammelnet fleet targeting anglerfish based on logbook data (2008–2019).

Hauls conducted with trammelnets and with reported catches of anglerfish species were selected from the overall dataset. Data were processed to estimate the proportion of each species by record and to eliminate potential reporting errors. Due to misreporting and quality of the report, only data from 2008 onwards were modelled. Observer data collected during a Data Collection Framework pilot study developed to collect information on the trammelnet fishery targeting anglerfish in Portuguese waters, showed that 92% of the hauls targeting anglerfish returned landings >50% in weight of these species (Moura *et al.*, 2016). So, a new variable (binary) was added to the dataset selected for modelling, specifying if the haul was likely to have targeted anglerfish or not. CPUE was estimated considering the haul as the effort unit.

A generalized linear mixed model (GLMM) was used to standardize CPUE. The following model was fitted to the response variable CPUE (landings of anglerfish by haul):

GLMM: (log(ANK) ~ Year + Month + Area + Target, random=Vessel)

considering as independent variables: Year, Month, Area (ICES statistical rectangle) and Target. The vessel identity (Vessel) was considered as the random variable, due to the high number of levels and relatively little data on most levels.

All the independent variables were modelled as categorical variables. Modelling was conducted in R software, using package "glmmTMB" (Brooks *et al.*, 2017). *Lophius budegassa* catch data were log transformed and modelled assuming the normal probability distribution.

Model´s adequacy was checked based on residual analysis. Estimated marginal means for the variable year were extracted using package "emmeans" (Lenth, 2020).

Figure 5.8 and Table 5.5 presents the estimated CPUE standardized series. Residual analysis and fit results are presented in Figures 5.9 and 5.10.

Table 5.5. Standardized CPUE index and corresponding standard error (se) for the Portuguese trammelnet fishery.

Year	CPUE (kg/haul)	se
2008	11.54	0.91
2009	15.34	1.19
2010	11.26	0.83
2011	18.45	1.41
2012	21.12	1.47
2013	21.59	1.51
2014	20.80	1.44
2015	15.82	1.09
2016	22.55	1.57
2017	23.80	1.64
2018	18.16	1.27
2019	17.95	1.29

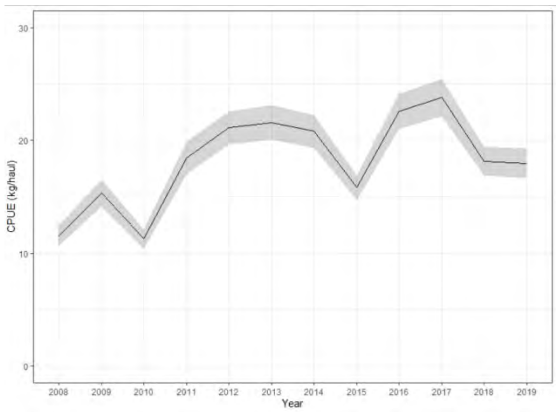

Figure 5.8. Standardized CPUE index (kg.haul^{-1}) for the Portuguese trammelnet fishery (2008–2019). Black solid line represents the standardized CPUE and the shaded grey area the respective standard errors.

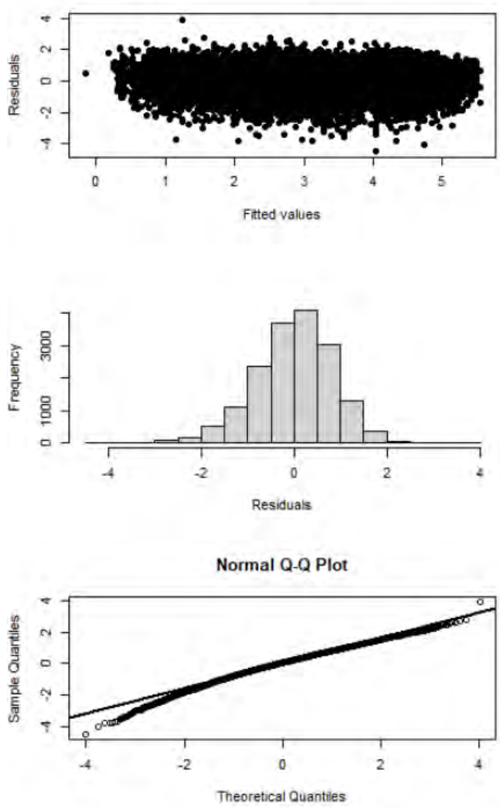

Figure 5.9. Standardized CPUE index (kg.haul-1) for the Portuguese trammelnet fishery (2008–2019): Model residuals. Top: fitted vs residuals; middle: residuals distribution plot; bottom: Q-Q plot.

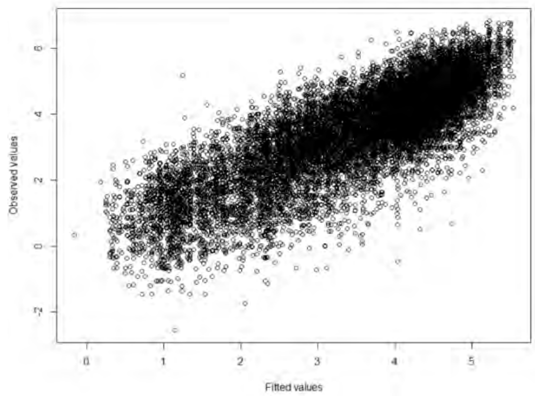

Figure 5.10. Standardized CPUE index (kg.haul^{-1}) for the Portuguese trammelnet fishery from (2008–2019): fitted vs observed values.

5.2.2.3 Combined index

WKMSYSPiCT suggested the development of a combined index for the fleets operating in the area and adequate for assessment. Common methods to combine CPUE indices are based on area occupied by the population or weighting by fishing effort (e.g., Quinn et al., 1982). In the case of ank.27.8c9a, spatial-models (e.g. Vector-Autoregressive Spatio-temporal model; Thorson, 2019), require georeferenced information not available for all the fleets. Moreover, dataseries correspond to different gears and/or with different effort units. Since the CPUE series available correspond to different time periods, only PT-TRF9a and PT- TRC9a fish were combined:

- SP-CORTR8c – 1982–2012
- PT- TRC9a – 1990–2019
- PT- TRF9a – 1989–2019
- PT- GTR – 2008–2019
- SP- ARSA Q4–1997–2019

Both indices estimates were derived from the same area and were combined by averaging the index value in each year centred by the mean of the full series.

Table 5.4 (Section 5.2.2.1.) presents the results for the common period 1990–2019. The combined index for the Portuguese trawl fleet (PT-TR9a) was used in the exploratory assessments with SPiCT.

5.2.3 Survey information and CPUE indices

The research surveys carried out in 8c and 9a cover the distribution of the stock (Figure 5.11). However, catchability is low in most of the surveys and the biomass indices available are not reliable for stock assessment of this species. A brief description of survey data available will be presented below.

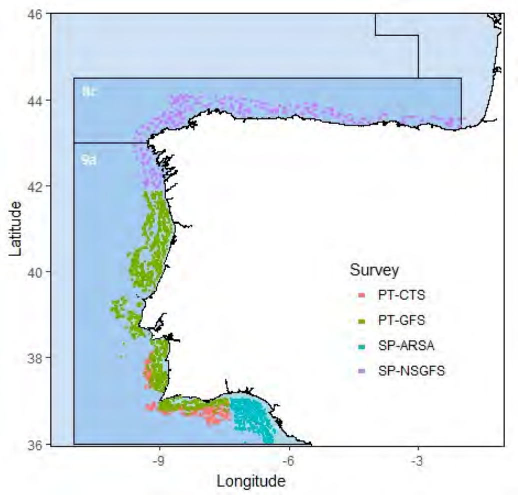

Figure 5.11. ***Lophius budegassa*** **in ICES divisions 8c and 9a. Research survey distribution.**

Southern Spanish Groundfish Survey on the Gulf of Cádiz (Southern part of Division 9a) (SP-ARSA)

The Southern Spanish Groundfish Survey on the Gulf of Cádiz is conducted in the southern part of ICES Division 9a, the Gulf of Cádiz. The covered area extends from 15 m to 800 m depth, during spring and autumn. The series covers the period 1993–2019, two surveys by year, and the abundance index (in number and in weight) and their associated variance, and length compositions are available. This survey, and particularly the Q4 survey, is a potential abundance index for the black anglerfish in divisions 8c9a (Figure 5.12). However, the low spatial coverage of the stock is a concern (ICES, 2018a).

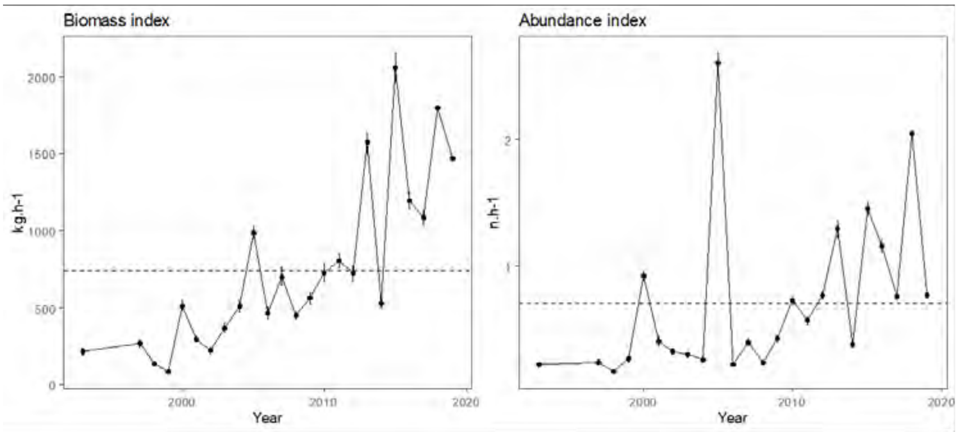

Figure 5.12. ***Lophius budegassa*** **in ICES divisions 8c and 9a. Total biomass and total abundance indices for the ARSA surveys in Q4 (1997–2019).**

Northern Spanish Shelf Groundfish Survey in the Cantabrian Sea and Off Galicia (SP-NSGFS)

The Spanish survey SP-NSGFS covers the northern Spanish shelf comprised in ICES Divisions 8c, and the northern part of 9a, including the Cantabrian Sea and off Galicia waters. The surveys are conducted from 30 to 800 m depth, usually starting at the end of the third quarter. Abundance index data (in number and in weight) are available for the period 1983–2019 with the exception of the year 1987 (Figure 5.13). This survey index may be a good indicator for smaller individuals (<20 cm) abundance, but not for the exploitable part of population.

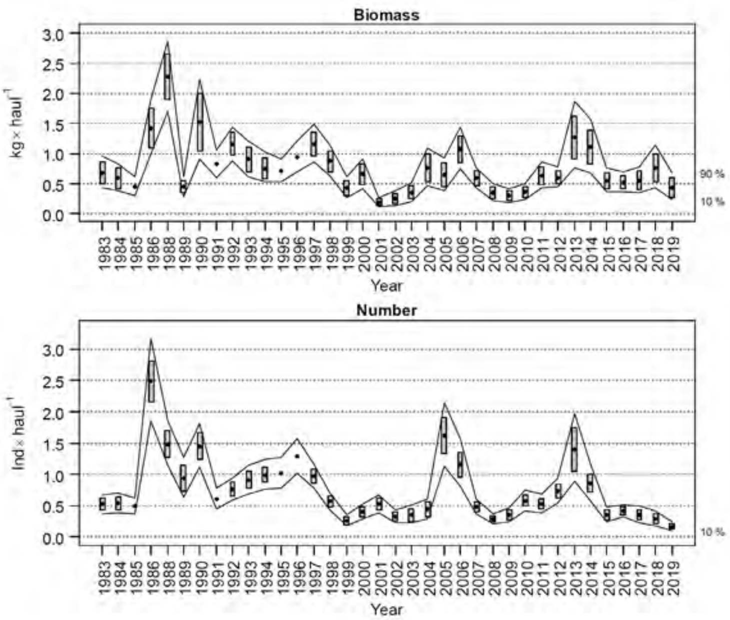

Figure 5.13. ***Lophius budegassa*** **in ICES divisions 8c and 9a. Biomass and abundance indices from the Northern Spanish Shelf Groundfish Survey in the Cantabrian Sea and Off Galicia (SP-NSGFS) (1983–2019).**

Portuguese Autumn Groundfish Survey (PtGFS-WIBTS-Q4)

Portuguese Autumn Groundfish Survey has been carried out in Portuguese continental waters since 1979 in the fourth quarter of the years. The survey covers all the Portuguese continental waters (ICES Division 9a) from 20–500 m depth. Abundance indices are available from 1989 to 2018 (surveys were not conducted in 2019 and 2010). The main objectives of the survey are to estimate the abundance and study the distribution of the most important commercial species in the Portuguese trawl fishery and to monitor the abundance and distribution of hake and horse mackerel recruitment. The low catchability of *Lophius* on these surveys, possibly related to the gear configuration, makes this series unsuitable to assess the abundance or biomass trends of these species.

Portuguese Crustacean Survey (PT-CTS (UWTV (FU 28–29)))

The PT-CTS (UWTV (FU 28–29)) is carried out in May–July and covers the southwest coast (Alentejo or FU 28) and the south coast (Algarve or FU 29). The main objectives are to estimate the abundance, to study the distribution and the biological characteristics of the main crustacean species, namely Norway lobster, rose shrimp and red shrimp. In addition, the survey provides data for other species that have been used for stock assessment purposes. Biomass and abundance indices for *L. budegassa* are available since 1997 (Figure 5.14) as well as length composition data. The survey was not conducted in 2019 and 2020. This survey is not used in the assessment of this stock due to the low catchability of the species.

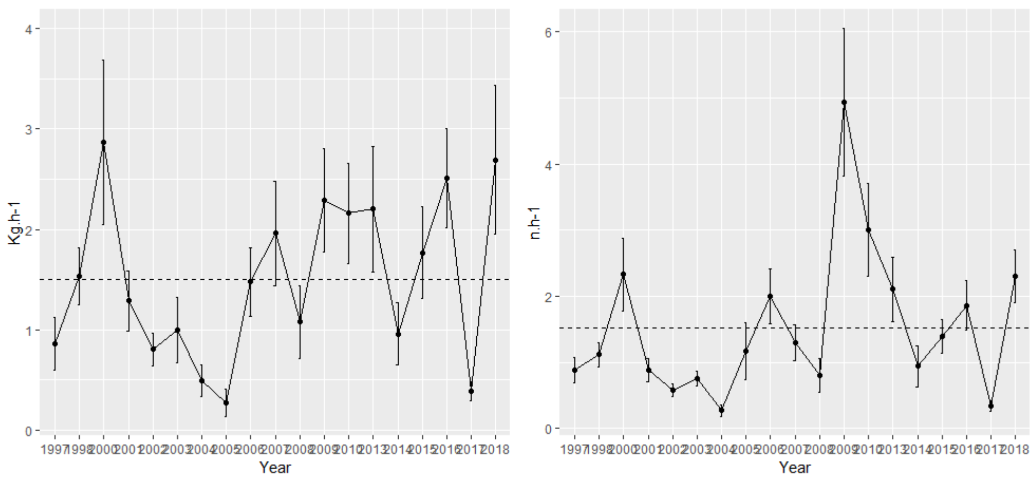

Figure 5.14. *Lophius budegassa* in ICES divisions 8c and 9a. Total biomass and total abundance indices for the Portuguese Crustacean Survey (PT-CTS (UWTV (FU 28–29))) (1997–2018; no survey in 2019 and 2020).

5.3 Stock assessment (ToR 3)

5.3.1 Exploratory assessments

Several runs were tested to check model performance and effects of using different datasets. Landings from 1980 to 2019 were included in all the models. The following CPUE, LPUE and biomass indices were considered:

- CPUE from PT-TRC9a (1990–2019);
- CPUE from PT-TRF9a (1989–2019);
- CPUE from PT-GTR-crust (2008–2019);
- LPUE from SP-CORTR8c (1982–2019);
- LPUE from SP-CORTR8c_port series (2013–2019);
- Biomass index from SP-ARSA-Q4 (1997–2019);
- Combined CPUE for PT-TR9a (1990–2019).

All the models used the settings below:

- Earlier time-step (years): 1/16 (default);
- Alpha - (Biomass observation and process errors ratio): estimated by the model (default priors);
- Beta - (Catch observation and process errors ratio): estimated by the model (default priors);
- CPUE and biomass indices were assigned to the middle of the year;
- Production curve shape: Schaefer (models tested presented better fit when this parameter was fixed; results not presented).

A summary of the results is presented in Table 5.6. The checklist for acceptance of a SPiCT model was followed (Mildenberger *et al*., 2020). Catch forecast for the year 2021 was estimated as described in Section 5.3.2 (Final assessment).

Model 1, which corresponds to the current assessment model but with standardized CPUE series for the Portuguese trawl fleets, shows autocorrelation for the PT-TRC9a, as previously. Models 2, 5, 7, 8 and 14–18 had no major issues, and could be considered to assess ank.27.8c9a. The remaining, with exception of models 3, 4, 10, 12 and 13, showed autocorrelation patterns for one of the fleets.

In all models, F/F_{MSY} and B/B_{MSY} at the end of the series, were below and above, respectively, the accepted reference points (see Section 5.3.2).

Table 5.6. Summary of input data and results for each exploratory run.

	PT-TRF9a	PT-TRC9a	SP-CORTR8c (fleet)	SP-CORTR8c (port)	PT-GTR	SP-ARSA	Checklist for acceptance	Mohn's rho		Results			Forecast
Period	1990–2019	1989–2019	1982–2012	2013–2019	2008–2019	1997–2019	Relevant issues	B/B_{MSY}	F/F_{MSY}	r	B/B_{MSY} (2020)	F/F_{MSY} (2019)	Catch_2021 (Fish at F_{MSY})
Area	9a	9a	8c	8c	9a	9a							
WGBIE 2020	x[1]	x[1]	x				Autocorrelation for PT-TRC9a.	-0.007	-0.010	0.48	1.665	0.219	---
1	x	x	x				Autocorrelation for PT-TRC9a.	-0.009	-0.014	0.39	1.724	0.205	2969
2		x	x		x		No issues.	0.003	-0.017	0.44	1.715	0.199	3174
3	x		x		x		Autocorrelation for SP-CORTR8c (fleet) and normality violation; Mohn's rho >0.2.	---	---	---	---	---	---
4	x		x				Autocorrelation for SP-CORTR8c (fleet) and normality violation; credible intervals for F/F_{MSY} span >1; Mohn's rho >0.2.	---	---	---	---	---	---
5		x	x		x	x	Autocorrelation for SP-CORTR8c (fleet).	0.019	-0.001	0.42	1.753	0.191	3093
6	x		x		x	x	Autocorrelation for SP-CORTR8c (fleet).	-0.097	0.092	0.30	1.464	0.278	2535
7	x						No issues.	-0.095	0.061	0.25	1.296	0.350	2109
7a[2]	x						No issues.	-0.124	-0.072	0.25	1.185	0.365	2055
7b[3]	x						Problems with Initial parameters estimates.	-0.091	-0.014	0.20	0.940	0.431	1779

[1] Non-standardized CPUE

	PT-TRF9a	PT-TRC9a	SP-CORTR8c (fleet)	SP-CORTR8c (port)	PT-GTR	SP-ARSA	Checklist for acceptance	Mohn's rho		Results			Forecast
Period	1990–2019	1989–2019	1982–2012	2013–2019	2008–2019	1997–2019	Relevant issues	B/B_{MSY}	F/F_{MSY}	r	B/B_{MSY} (2020)	F/F_{MSY} (2019)	Catch_2021 (Fish at F_{MSY})
Area	9a	9a	8c	8c	9a	9a							
8	x				x		No issues.	-0.124	0.098	0.26	1.315	0.332	2192
9	Combined model		x				Autocorrelation for SP-CORTR8c (fleet).	-0.003	0.03	0.41	1.653	0.223	2989
10	Combined model		x	x			Autocorrelation for SP-CORTR8c (fleet); problems with Initial parameters estimates.	0.006	-0.003	0.43	1.728	0.214	3083
11	Combined model		x	x	x		Autocorrelation for SP-CORTR8c (fleet).	0.000	-0.003	0.41	1.685	0.223	2999
12[2]	x		x				Autocorrelation for SP-CORTR8c (fleet); credible intervals for F/FMSY span >1; Mohn's rho close to 0.2.	-0.135	0.179	0.30	---	---	---
13[3]	x		x				Autocorrelation for SP-CORTR8c (fleet); normality violation; credible intervals for F/F_{MSY} span >1	-0.059	-0.019	0.21	---	---	---
14[2]		x	x				No issues.	0.048	0.007	0.39	1.848	0.168	3822
15[3]		x	x				No issues.	0.023	0.025	0.37	1.725	0.168	3958

[2] ank8c9a$priors$logbkfrac = c(log(0.5),0.5,1)

[3] ank8c9a$priors$logbkfrac = c(log(0.3),0.5,1)

	PT-TRF9a	PT-TRC9a	SP-CORTR8c (fleet)	SP-CORTR8c (port)	PT-GTR	SP-ARSA	Checklist for acceptance	Mohn's rho		Results			Forecast
Period	1990–2019	1989–2019	1982–2012	2013–2019	2008–2019	1997–2019	Relevant issues	B/B_{MSY}	F/F_{MSY}	r	B/B_{MSY} (2020)	F/F_{MSY} (2019)	Catch_2021 (Fish at F_{MSY})
Area	9a	9a	8c	8c	9a	9a							
16[2]		x	x			x	No issues.	0.057	-0.007	0.38	1.848	0.163	3930
17[3]		x	x			x	No issues.	0.029	0.024	0.35	1.724	0.164	4071
18		x	x			x	No issues.	0.087	-0.003	0.37	1.802	0.163	3992
19[4]		x	x			x	Problems with initial parameters estimates (NA).	0.103	-0.048	0.17	2.005	0.164	4035
20		x	x	x	x		Shapiro test (PT-GTR)	0.036	-0.043	0.45	1.846	0.198	3262
21	Combined model						No issues.	-0.055	0.062	0.40	1.616	0.228	2991
22[2]	Combined model						No issues.	-0.073	0.076	0.39	1.585	0.229	3016

[4] No prior for the production curve

5.3.2 Final assessment

The final model was selected based on the fit, adequacy of the CPUE data to inform on the stock status and reliability of the short-term forecast.

Models with the PT-GTR and SP-CORTR8c (port series) as input data were not considered due to the inadequacy of the series for the assessment of the stock.

The CPUE series PT-TRF9a, PT-TRC9a and SP-CORTR8c (fleet series) show similar trends over time, with relatively high CPUE values at the beginning of the series, a decrease and relatively low values until 2010 and an increase in 2010. However, the SP-CORTR8c (fleet series) ends in 2012 and the other two series show different trends since 2013.

WKMSYSPiCT highlighted that the PT-TRC9a trend in the last years is supported by SP-ARSA. Models 14 to 19 only use PT-TRC9a or PT-TRC9a and SP-ARSA as biomass indices, but short-term forecasts lead to an estimated catch at F_{MSY} ~4000 t. These values are higher than the maximum reported for the stock (3872 t in 1987), after which a decrease in landings was observed. Moreover, both series suggest relatively high values of biomass for the stock in the last years, which do not seem to adequately explain the low landings value reported in 2019, the lowest in the time-series (and without TAC constraints).

The differences observed between PT-TRC9a and PT-TRF9a in the last years of the series can be related with the different depth distribution of the fleets: CPUE data from both fleets are restricted to the same area but operate at different depths, with the crustacean fleet fishing at deeper depths (200–800 m deep) than the fish fleet (<500 m deep) (Silva *et al*., 2009). Higher yields are expected at 200–400 m deep, where the target fisheries operate (Moura *et al*., 2018) and considered the core distribution of the stock. Such depths are covered by the PT-TRF9a which also has the highest CPUE values.

Considering the above, model 7a, which uses as biomass series the PT-TRF9a, was accepted for assessment of ank.27.8c9a (Figure 5.15). In this model, a prior for B/K of 0.5 was assumed, as exploitation was likely to occur before the beginning of the available time-series. Despite target fisheries development in the late 1970s, previously, the species was likely to be caught and discarded in other fisheries.

Main results are shown in Figures 5.16 to 5.18 and in Table 5.7. No significant bias or autocorrelation were found and both QQ-plot and the Shapiro test show normality in the residuals. Some retrospective pattern is observed but all peels are within the confidence intervals and Mohn's rho is <0.2 (of -0.124 for B/B_{MSY} and of -0.072 for F/F_{MSY}).

Considering the adopted reference points proposed for production models by ICES (ICES, 2016), and accepted in the past benchmark for this stock (ICES, 2018a), F/F_{MSY} in 2019 is below F_{MSY} and B/B_{MSY} in 2020 is above B_{MSY}, which does not change the perception of the status of the stock (see ICES, 2020b).

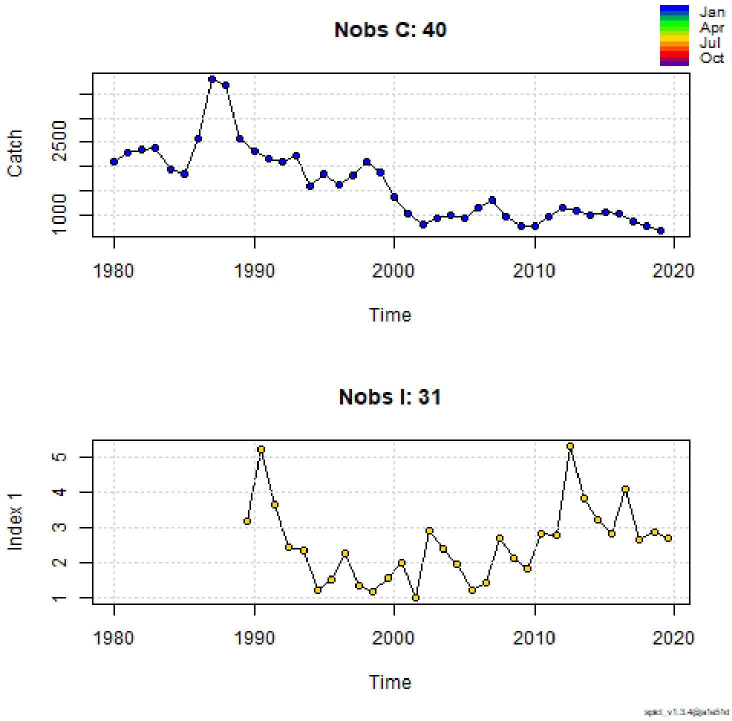

Figure 5.15. Final assessment model for ank.27.8c9a, input data. Top: landings from 1980 to 2019; bottom: commercial CPUE from PTTRF9a, 1989 to 2019.

Table 5.6. Final assessment model for ank.27.8c9a, parameter estimates, reference points, estimated states and predictions.

Parameter estimates	estimate	cilow	ciupp	log.est	
alpha	2.434959e+00	7.723421e-01	7.676680e+00	0.8899298	
beta	1.354030e-01	2.299130e-02	7.974292e-01	-1.9994999	
r	2.461972e-01	9.275500e-02	6.534751e-01	-1.4016225	
rc	2.461972e-01	9.275500e-02	6.534751e-01	-1.4016225	
rold	2.461972e-01	9.275500e-02	6.534751e-01	-1.4016225	
m	1.776053e+03	1.210762e+03	2.605273e+03	7.4821489	
K	2.885578e+04	1.150994e+04	7.234237e+04	10.2700658	
q	1.897000e-04	6.910000e-05	5.209000e-04	-8.5699270	
sdb	1.214022e-01	4.464330e-02	3.301392e-01	-2.1086462	
sdf	1.883506e-01	1.245092e-01	2.849264e-01	-1.6694500	
sdi	2.956094e-01	2.148822e-01	4.066643e-01	-1.2187164	
sdc	2.550320e-02	4.616700e-03	1.408844e-01	-3.6689498	

Deterministic reference points	estimate	cilow	ciupp	log.est	
Bmsys	1.442789e+04	5754.9697352	3.617119e+04	9.576919	
Fmsys	1.230986e-01	0.0463775	3.267375e-01	-2.094770	
MSYs	1.776053e+03	1210.7619220	2.605273e+03	7.482149	

Stochastic reference Points	estimate	cilow	ciupp	log.est	rel.diff.Drp
Bmsys	1.393753e+04	5603.5888334	3.466611e+04	9.542340	-0.03518312
Fmsys	1.194298e-01	0.0447364	3.188339e-01	-2.125026	-0.03071924
MSYs	1.662757e+03	1164.0079245	2.375209e+03	7.416232	-0.06813744

States	estimate	cilow	ciupp	log.est	
B_2019.94	1.645435e+04	6355.5574280	4.259984e+04	9.7083453	
F_2019.94	4.015640e-02	0.0150715	1.069921e-01	-3.2149741	
B_2019.94/Bmsy	1.180579e+00	0.5922933	2.353170e+00	0.1660051	
F_2019.94/Fmsy	3.362341e-01	0.1432919	7.889724e-01	-1.0899478	

Predictions	prediction	cilow	ciupp	log.est	
B_2021.00	1.743146e+04	6948.9615634	4.372680e+04	9.7660320	
F_2021.00	4.015650e-02	0.0140346	1.148978e-01	-3.2149700	
B_2021.00/Bmsy	1.250685e+00	0.6324075	2.473427e+00	0.2236917	
F_2021.00/Fmsy	3.362355e-01	0.1321389	8.555717e-01	-1.0899436	
Catch_2020.00	6.807007e+02	480.4991133	9.643169e+02	6.5231227	
E(B_inf)	2.222411e+04	NA	NA	10.0089330	

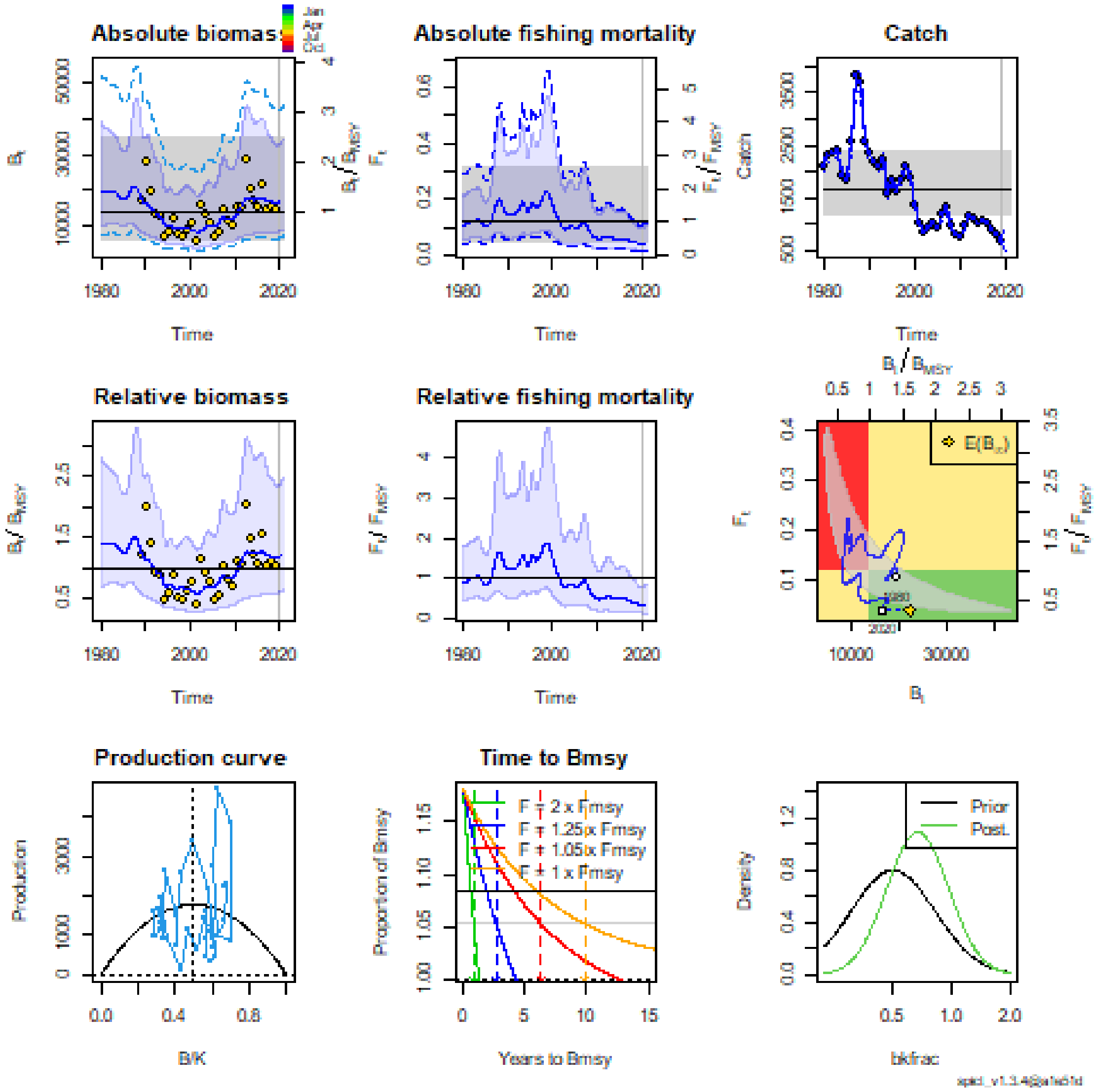

Figure 5.16. Final assessment model for ank.27.8c9a.

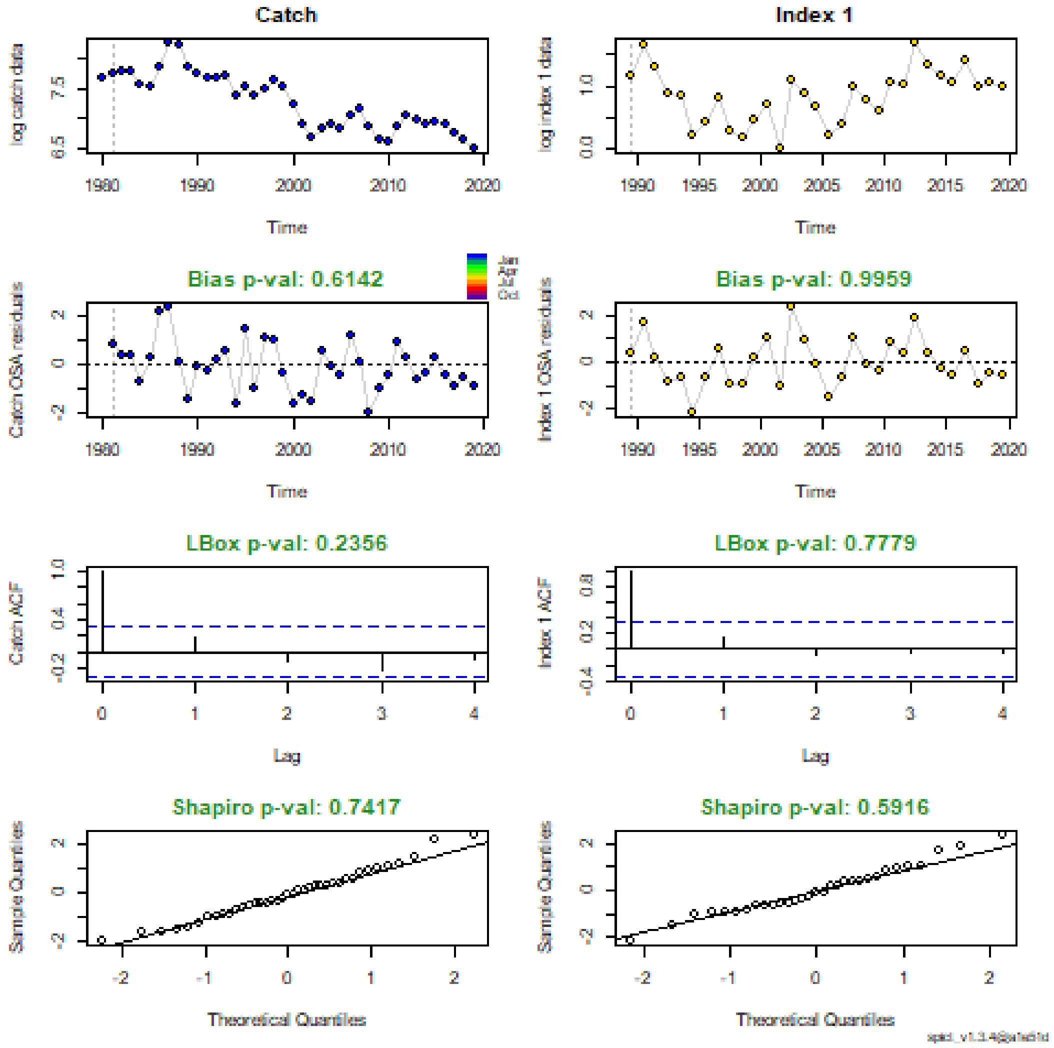

Figure 5.17. Final assessment model for ank.27.8c9a, diagnostics. Row1, Log of the input dataseries. Row 2, OSA residuals with the p-value of a test for bias. Row 3, Empirical autocorrelation of the residuals with tests for significant autocorrelation. Row 4, Tests for normality of the residuals, QQ-plot and Shapiro test.

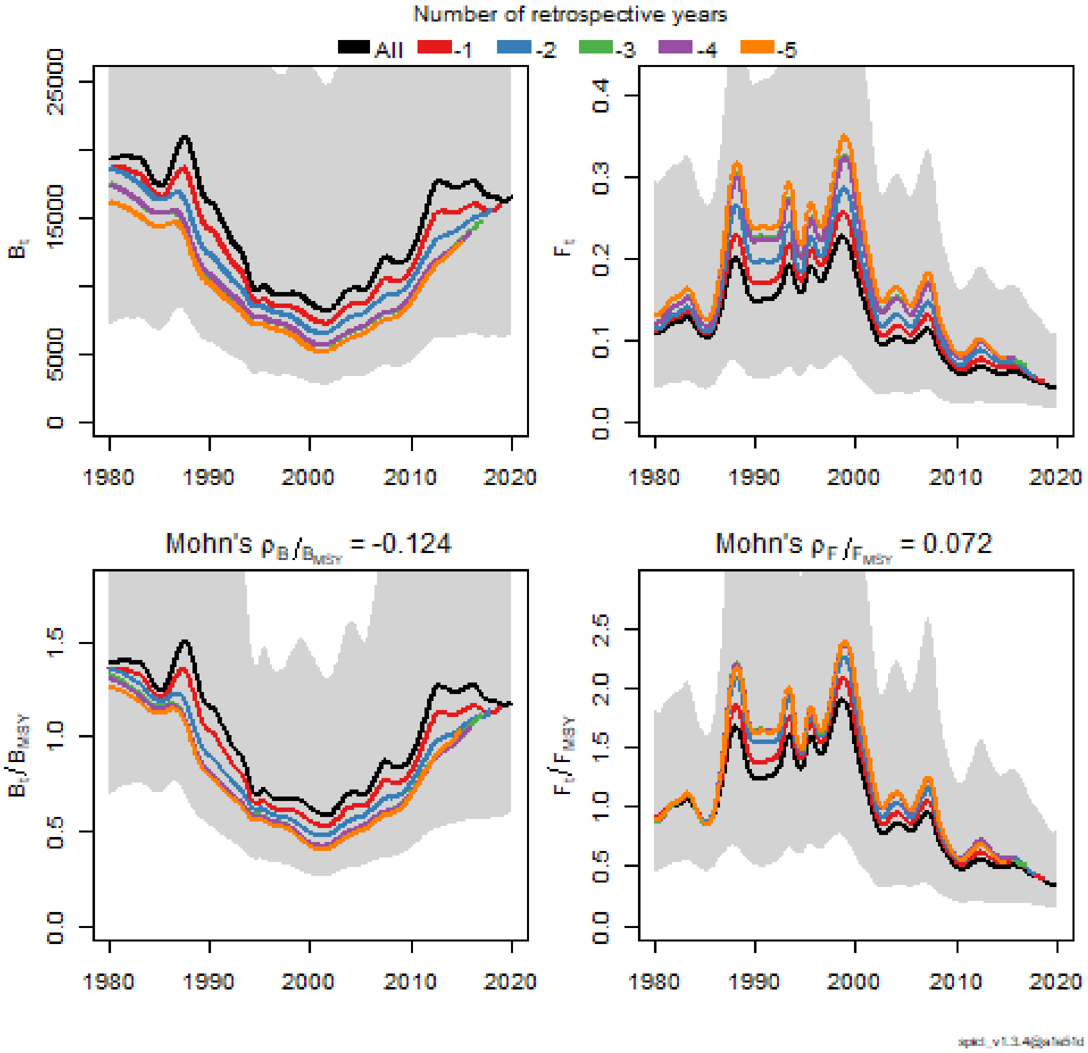

Figure 5.18. Final assessment model for ank.27.8c9a, retrospective analysis (5 peels). Upper panel, absolute biomass and fishing mortality. Lower panel, relative biomass and fishing mortality. Grey regions represent 95% CIs.

5.4 Catch forecast (ToR 3)

Short-term forecast used the F from the last year of the series (in this case, 2019) as the F in the intermediate year. Table 5.8 presents the results.

Table 5.8. Short-term forecast results, considering the intermediate year (2020) and four management scenarios.

Scenarios	Catch	B/B_{MSY}	F/F_{MSY}
1. F=0	0.0	1.36	0.00
2. $F=F_{sq}$	715.9	1.31	0.34
3. $F=F_{MSY}$	2054.7	1.22	1.00
4. $F=F_{MSY}$_C_fractile	1853.6	1.23	0.90

5.5 Future considerations/recommendations

Standardization methods for all fleets can be improved to accommodate targeting effects using more adequate methodologies (e.g. clustering methods) as well as higher spatial resolution. Spatial information should also be better understood to disentangle possible different stock trends. In addition, more accurate information on stock biology and ecology as well as on the behaviour of the fisheries is desirable to understand and validate some biomass trends (SP-ARSA, PT-TRC9a).

5.6 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

In general, the data preparation for this assessment followed the guidelines discussed at the data meeting of WKMSYSPiCT (Benchmark Workshop on the development of MSY advice for category 3 stocks using Surplus Production Model in Continuous Time) held in November. The CPUE data derived for commercial fleets have now been standardized to account for spatio-temporal and random vessel effects, although the resolution of the area effect can be improved (e.g. using smaller areas or clusters), and historical catch data have been analysed. In addition, future effort to improve the CPUE standardization should explore using targeting effects as co-variates by making use of the species composition in the catches (Parker *et al*., 2017; Thorson *et al*., 2016; Winker *et al*., 2014, 2013). We advise, however, against targeting factors that uses catch proportions because this is likely to result in removing abundance signal of interest (e.g. Hoyle *et al*., 2014).

It is evident, that there is a conflict between some of the indices used in the assessment, i.e. the CRU and the FISH index, with the CRU index increasing and the FISH index being stable or even slightly declining in latest years. The conflict might be due to area differences in stock distribution or depletion and/or differences in selectivity. SPiCT is not able to account for these effects, but given the large contrast in the indices, it would be important to model those as well in the future or improve the indices themselves. Not all indices might be equally suitable and a careful evaluation of criteria for index inclusion could be useful for future assessments of this stock. As a result of this conflict, SPiCT produces effectively an average of the two indices when estimating biomass and F trends when both indices are included. In addition, some SPiCT runs predicted high biomass levels ($B > B_{MSY}$) in 1992, which would imply that limited fishing took place before 1982. However, from the available landings data, this assumption seems not to be supported as fisheries started likely well before 1982, considering that catches in 1982 already exceeded MSY. The final chosen SPiCT model imposed a prior in the initial depletion level and included only the FISH index, since this index was considered more appropriate due to a better coverage of the stock distribution. This was considered adequate for addressing the issues outlined above.

In WKTDSA (Workshop on Tools and Development of Stock Assessment Models Using a4a and Stock Synthesis), we explored a Stock Synthesis (SS) model of the same stock, assuming very low initial catches, which is similar to SPiCT assumption. The results between SS and SPiCT are rather similar in term both of trend, value and stock status (Figure 5.6.1). However, the model diagnostics of this model are less supported when compared to an alternative run where we changed the assumption of the initial catches and assuming that those are similar to 1982 (i.e. average of 1982–1985; i.e. fisheries started before 1982).

In general, SS results are similar to SPiCT for the latest period (both in terms of trend and stock status) but largely differs in the start of the time-series (Figure 5.6.1). More importantly, the diagnostic of the latter model is much improved, especially hindcasting, retrospective and forecast Mohn´s rho (Figure 5.6.2). Like SPiCT, the initial SS model cannot explain the diverging trends between the CRU and the FISH index, but the fits are generally better to CRU index, which shows the clearly superior prediction skill for the run with high initial catches. The CRU index also appears to be consistent with the biomass index from Southern Spanish Groundfish Survey on the Gulf of Cádiz - 9aS (SP-ARSA; Figure 5.6.3).

To further corroborate the current reference model, we recommended to present the following additional runs, residual diagnostics and retrospective analysis during the benchmark workshop with the following index combinations, and by using a lower initial depletion prior, e.g. logbkratio = c(log(0.5),0.5,1) and c(log(0.3),0.5,1):

1. SPCORTR8c + PT-FISH;
2. SPCORTR8c + PT-CRU;
3. SPCORTR8c + PT-CRU + Cadiz Survey (corroborate).

The results of the additional runs confirmed the robustness and stability of the model, although issues remain on the status of the stock in the beginning of the time-series and about the absolute level of biomass in recent years. The model 7a with logbkratio = c(log(0.5),0.5,1) was chosen based on slightly improved diagnostics, especially the retrospective.

Conclusions

Thus, given the results presented thus far, we consider that the SPiCT assessment model 7a of Black-bellied anglerfish in divisions 8c and 9a is robust enough for the time being to give advice. The main challenge for this stock relates to the use of commercial CPUE series and how they are standardised. Care must be taken when selecting appropriate time-series to include in the model, and that these are properly standardised. It must be recommended to continuously re-evaluate the procedure for commercial CPUE standardisation, since fleet behaviour including targeting may change over time unlike for scientific surveys. Dedicated ICES workshops addressing the issue of commercial CPUE standardisation in general should also be considered, since this seems is a common and challenging problem for many stocks.

Furthermore, given the considerations outlined above, we suggest that, in line also with WKTDSA, the SS integrated model should be developed and finalized for the next benchmark, which should be based on improved standardization methods to account for potential changes in q (targeting) and assumptions on technological creeping, for area differences in stock structure and fisheries, and also explore the effect of initial catches and/or reconstructed historical catches in the SS model results through extensive diagnostics.

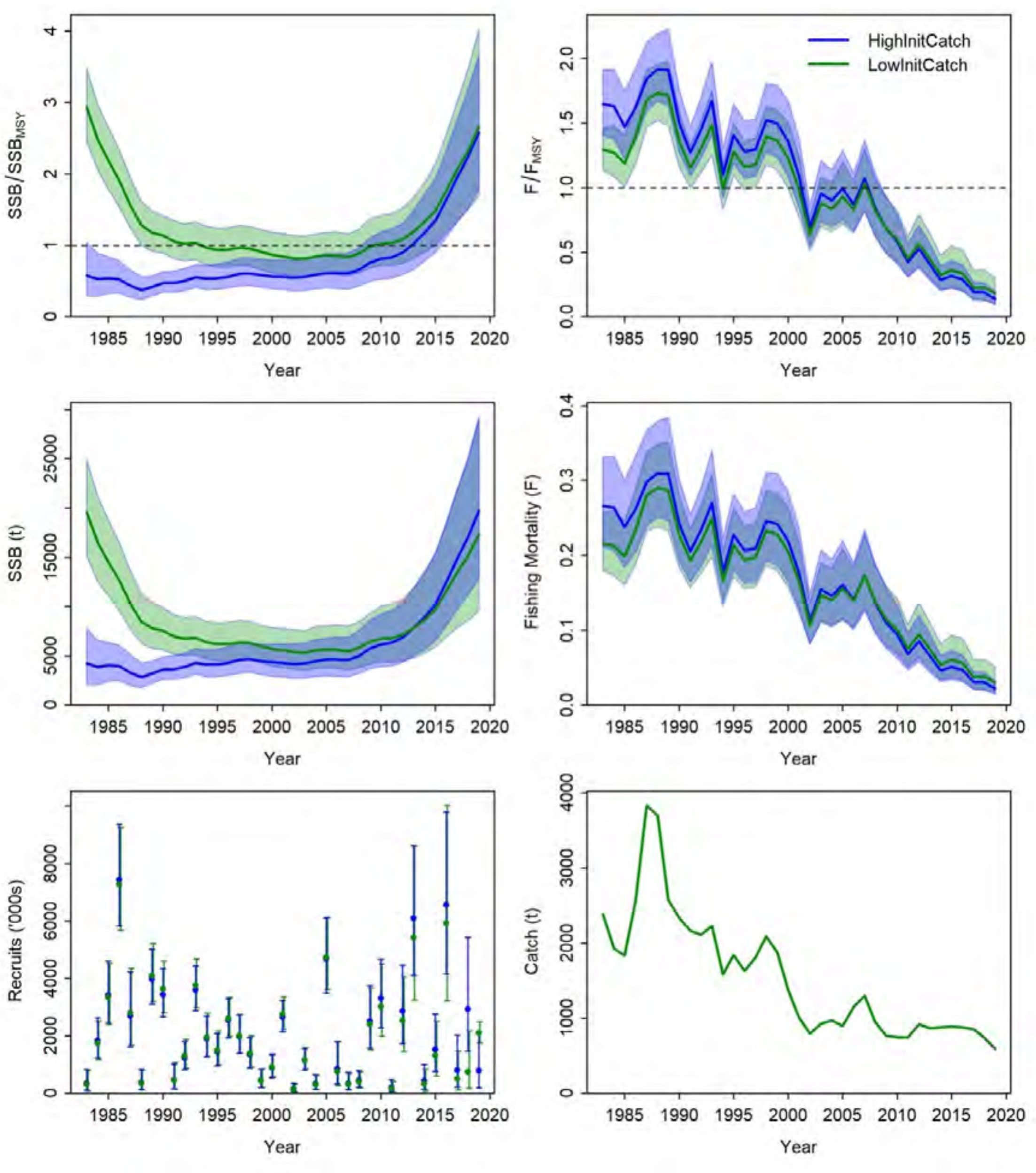

Figure 5.6.1. Estimated trajectories from two different Stock Synthesis model runs assuming low and high initial catches at the start of the catch time-series.

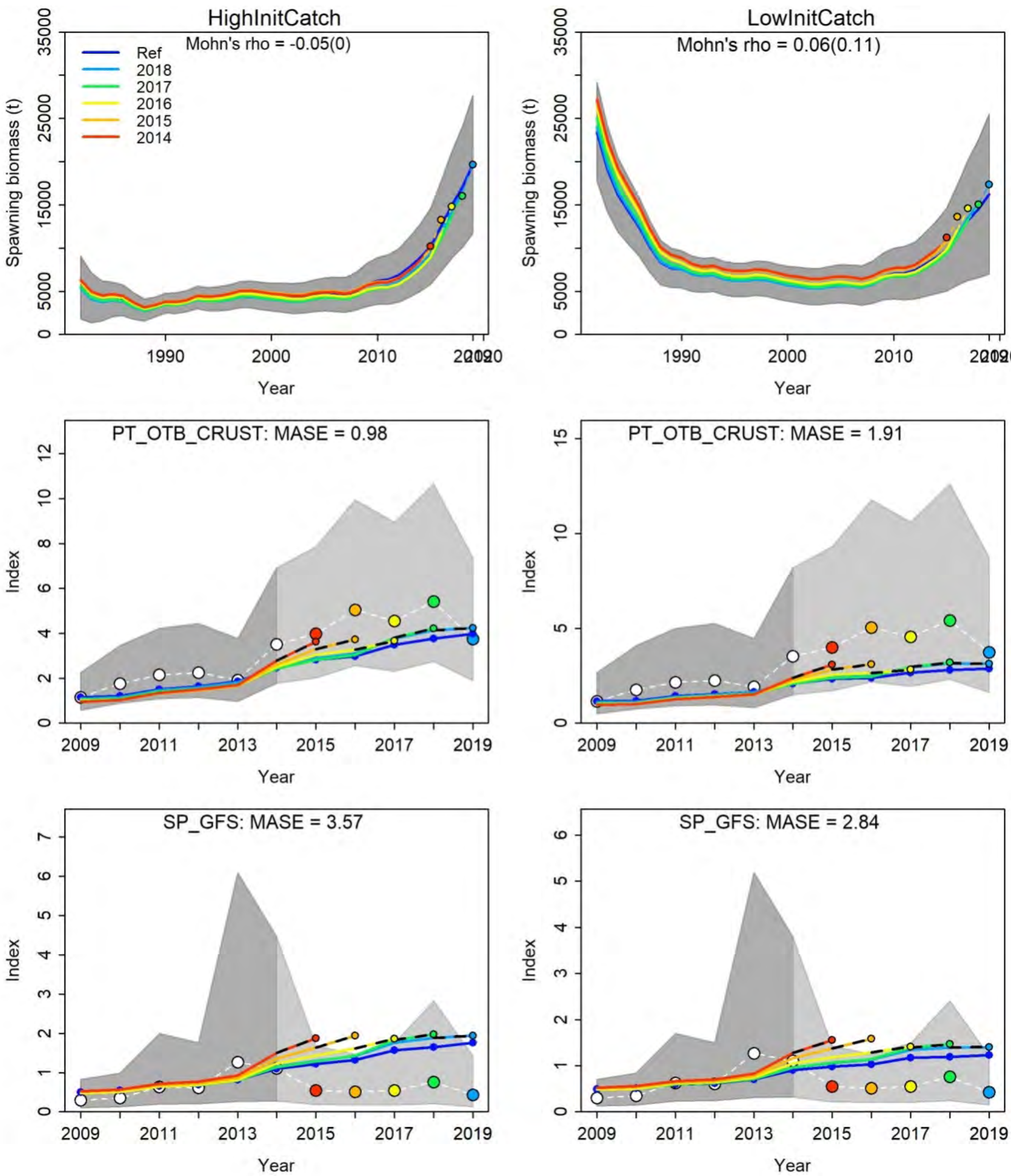

Figure 5.6.2. Model diagnostics for two different Stock Synthesis model runs assuming low and high initial catches at the start of the catch time-series, showing results of retrospective bias and forecast bias (in brackets), and hindcast-cross validation with prediction skill (MASE) conducted on two indices.

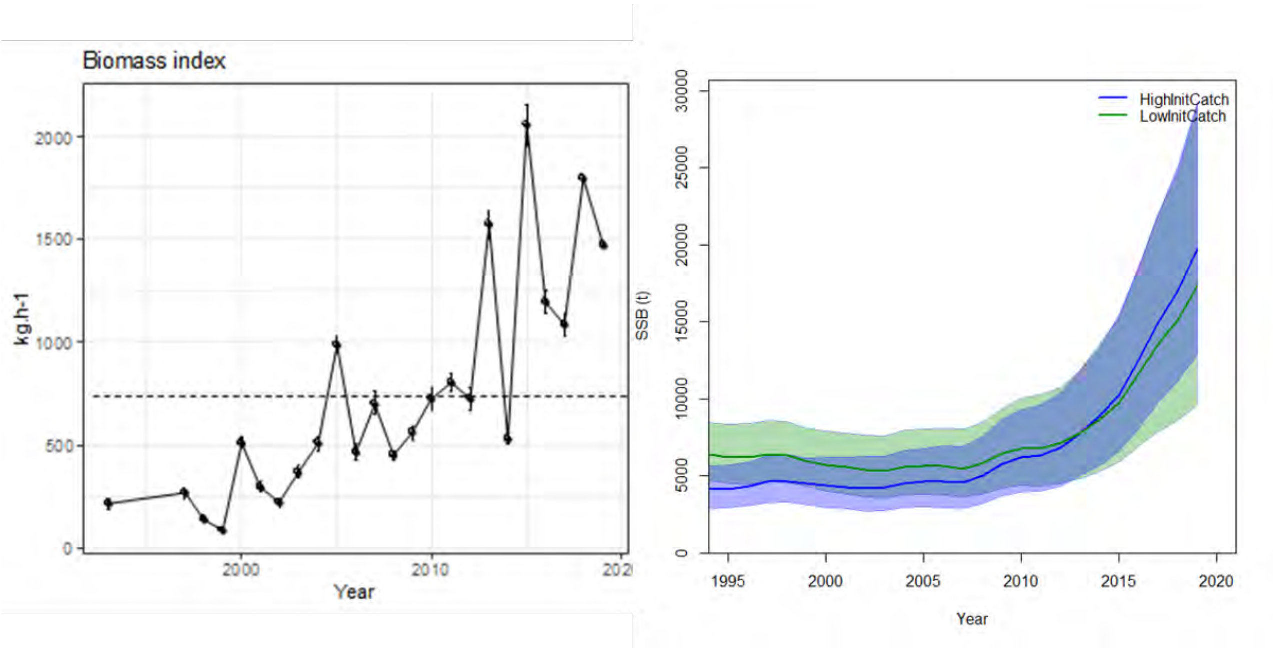

Figure 5.6.3. Visual comparison between the Southern Spanish Groundfish Survey on the Gulf of Cádiz - 9aS (not included in the model) and the SSB trends from two Stock Synthesis runs.

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6 Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (pol.27.89a)

6.1 Introduction

Pollachius pollachius (Linnaeus, 1758) is restricted to the Northeast Atlantic with a main distribution from the Portuguese continental coast northwards around the British Isles, into the Skagerrak and along the Norwegian coast where it is fairly common up to the Lofoten Islands.

Pollack is a bentho-pelagic species. Outside the breeding season, it does not form large schools, but it is rarely solitary. During reproduction, individuals come together in dense formations. Juveniles live along the coast at least during their first two years; they move offshore, gaining depth (40 to 100 m) during their third year (Moreau, 1964; Quéro and Vayne, 1997). According to Moreau (1964) reproduction occurs at maximum depths of 150 m.

Data from the fishery indicate three main areas of exploitation, so based on a pragmatic approach three different stock units are distinguished (ICES, 2012): the southern European Atlantic shelf (ICES Subarea 8 and Division 9a), the Celtic Seas (ICES subareas 6 and 7), and the North Sea (ICES Subarea 4, including divisions 7d and 3a).

Pol.27.8.9a is mainly exploited by France and Spain, with minor contribution to landings from Portugal. In the last ten years, France was responsible for 77% of the commercial landings of the stock and Spain for 18%. In recent years, netters and longliners are catching the 54% and 35% of landings, respectively. Trawl and other gears catch the remaining 21% of landings.

Although it is known that the recreational catches may be considerable, they have not been quantified.

Currently, pol.27.8.9a is considered a data-limited stocks without information on abundance or exploitation, and it is classified as ICES Category 5 stock. The last management advice was provided in 2019, and ICES advised that commercial landings should be no more than 1131 tonnes in each of the years 2020 and 2021.

The first objective of this study is to compile and evaluate the available data of pol.27.8.9a in order to apply a stochastic production model in continuous time (SPiCT) (Pedersen and Berg, 2007). The second objective was to test different model configurations and values of priors to achieve a robust model for the stock.

6.2 Input data for stock assessment

Commercial catches

A time-series of landings has been obtained from EuroStat, the statistical office of the European Union, since 1950; however, data show much more reliable and complete from 1977 onwards. At the same time, the national laboratories of countries with Pollack catches have provided more detailed data of landings, disaggregated by gear, since 2001. Since 2015, official data by country are uploaded to the InterCatch database.

The time-series of commercial landings is available by country and area for the period 1979–2019 (Table 6.1). The values recorded for Spain in 1984 and 1985 are considered too high to be realistic, and it is recommended they not be taken into account. There is a missing value in the series for France in 1999. In order to complete the series, a value for France in 1999 was calculated as the average of the previous and next year of French landings, resulting in 1125 t. The assumed total landings for the stock in 1999 are 1282 t. The landings for Spain in Division 8 for year 1982 are considered too low (82 t) to be reliable, and because of that the Spanish landings for 1982 were estimated by interpolation, resulting in 843 tonnes and corresponding 811 t to Division 8.

Table 6.1. Commercial landings by area for each country participating in the fishery. Values are in tonnes. Red values show estimated quantities by interpolation.

Year	Subarea 8					Division 9.a			Total official landings	Unallocated	Total	Total. Interpolated
	Belgium	Spain	Spain.Interpolated	France	France. Interpolated	UK	Spain	Portugal				
1979	0	1021		2221		0	0	0	3242	0	3242	3242
1980	1	1576		2158		0	0	0	3735	0	3735	3735
1981	1	902		2326		0	0	0	3229	0	3229	3229
1982	2	85	811	2185		2	32	0	3117	0	3117	3032
1983	0	581		2652		0	203	0	3436	0	3436	3436
1984	0	1606		2351		1	642	0	4600	0	4600	4600
1985	0	2304		2769		23	636	0	5732	0	5732	5732
1986	0	437		2127		5	237	0	2806	0	2806	2806
1987	0	584		2022		1	308	3	2918	0	2918	2918
1988	3	476		1761		6	329	7	2582	0	2582	2582
1989	13	214		1682		4	57	3	1973	0	1973	1973
1990	14	194		1662		2	27	1	1900	0	1900	1900
1991	1	221		1867		1	76	2	2168	0	2168	2168
1992	2	154		1735		0	65	2	1958	0	1958	1958
1993	3	135		1327		0	47	1	1513	0	1513	1513
1994	3	157		1764		0	28	3	1955	0	1955	1955
1995	6	153		1457		2	59	2	1679	0	1679	1679
1996	8	137		1164		0	43	2	1354	0	1354	1354
1997	2	152		1167		1	54	2	1378	0	1378	1378
1998	1	152		956		0	55	1	1165	0	1165	1165
1999	0	120		na	1125	0	36	1	157	0	157	1282
2000	0	121		1294		0	49	15	1479	0	1479	1479
2001	0	346		1278		0	81	41	1746	0	1746	1746
2002	0	170		1722		0	35	45	1972	0	1972	1972
2003	0	142		1450		1	39	31	1663	0	1663	1663
2004	0	211		1343		0	90	12	1656	70	1726	1726
2005	0	306		1552		0	132	0	1990	-4	1986	1986
2006	0	251		1596		171	102	0	2120	6	2126	2126
2007	0	198		1375		62	103	5	1743	104	1847	1847
2008	0	265		1732		64	128	31	2220	93	2313	2313
2009	0	218		1371		41	68	3	1701	111	1812	1812
2010	0	265		1170		44	91	2	1572	110	1682	1682
2011	0	322		1475		27	104	2	1930	102	2032	2032
2012	0	159		1131		2	139	2	1433	87	1520	1520
2013	0	251		1346		8	110	3	1718	93	1811	1811
2014	0	185		1612		19	93	1	1910	49	1959	1959
2015	0	195		1244		37	78	18	1573	37	1610	1610
2016	0	186		1292		25	111	28	1642	19	1661	1661
2017	0	128		1219		0	95	38	1480	1	1481	1481
2018	0	135		1220		0	12	33	1513	0	1513	1513
2019	0	174		1189		0	143	57	1562	0	1562	1562

Discard data are available for the main countries and gears from 2015 to 2019 (Table 6.2). Data were extracted from InterCatch database. Discards represented an average of 2.5% of total commercial catches and, following the ICES guidelines, they can be considered negligible.

Table 6.2. Discards by country and gear. Values are in tonnes.

	France			Spain			Portugal
Year	**Nets**	**Trawl**	**Lines**	**Lines**	**Nets**	**Trawl**	**Trawl**
2015	28.1	0	0	0	3.5	0	0
2016	83.1	5.4	4.3	0	0.4	0	0
2017	18.6	0	0	0	0	0	0
2018	38.7	0	0	0	0	2.8	0
2019	8.2	0	6.1	0	0	0	0

Recreational catches

Recreational catches of pollack may be considerable but they have not been quantified.

Length composition of commercial landings

Length distribution of landings is available for some métiers and quarters for France (2010–2019), Spain (2015-2019) and Portugal (2019) (Figure 6.1). The métiers and quarter coverage of the length sampling has changed from year to year, and the sampling level has been extremely low in the last two years. These issues reduce the representativeness and the quality of the length composition of landings. A set of length compositions of commercial landings, annual and gear-combined, for the period 2010–2019 were raised to total landings using information from ROMELIGO project (2010–2014) (ICES, 2019) and from InterCatch (2015–2019) (Figure 6.2). The length composition of landings was employed to estimate the length of first capture (Lc) of pol.27.89a following the calculation defined for Length-Based-Indicators (ICES, 2015). Lc was estimated at 34 cm and was used as input data to calculate the *r* priors. The Lc is lower than the Lmat (41 cm), and this is related with the fact that the Minimum Recommended Conservation Size is set at 30 cm and discards of pollack are considered negligible (< 5% catches).

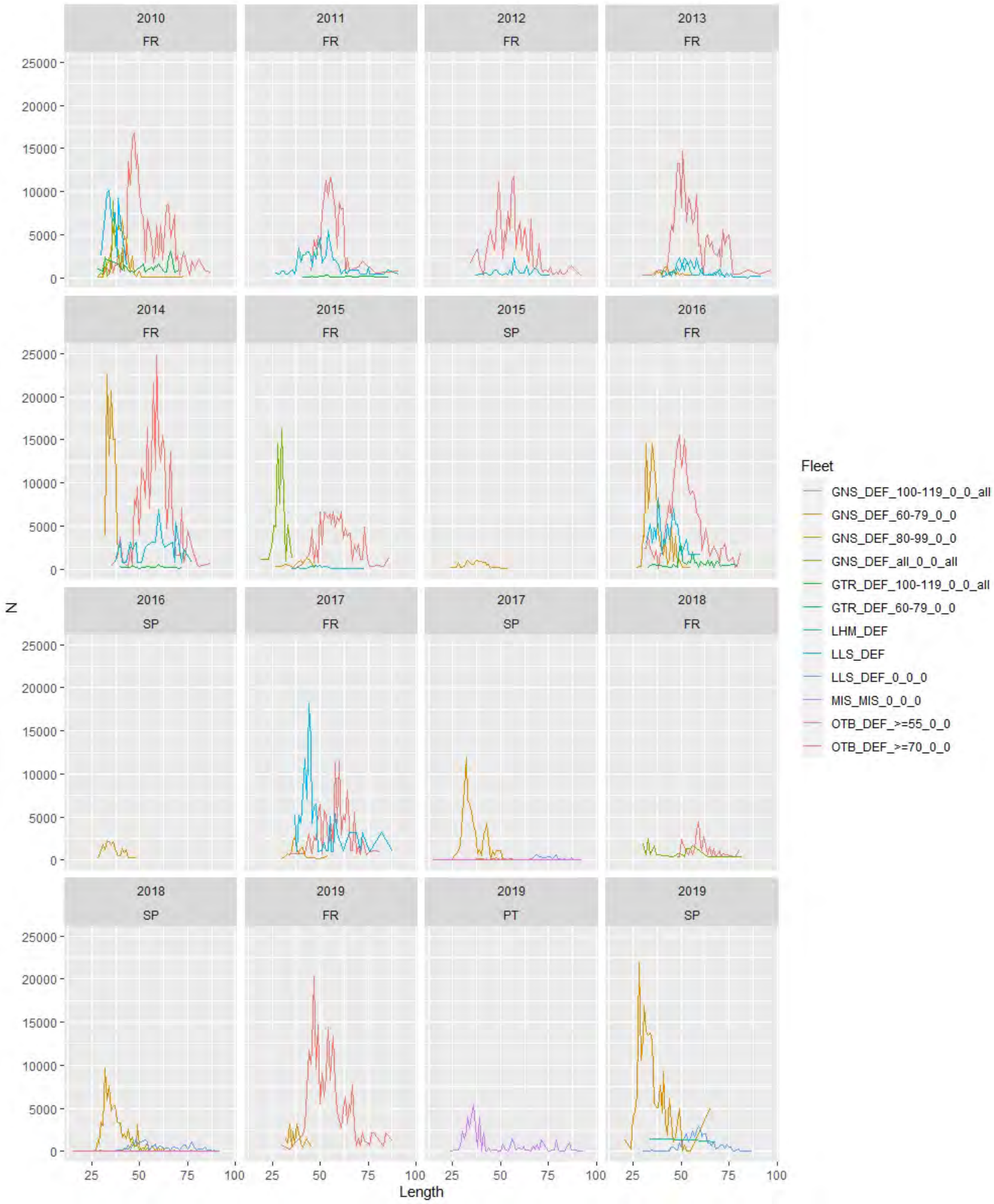

Figure 6.1. Annual length distribution of sampled métiers by country and year. FR: France, SP: Spain, PT: Portugal.

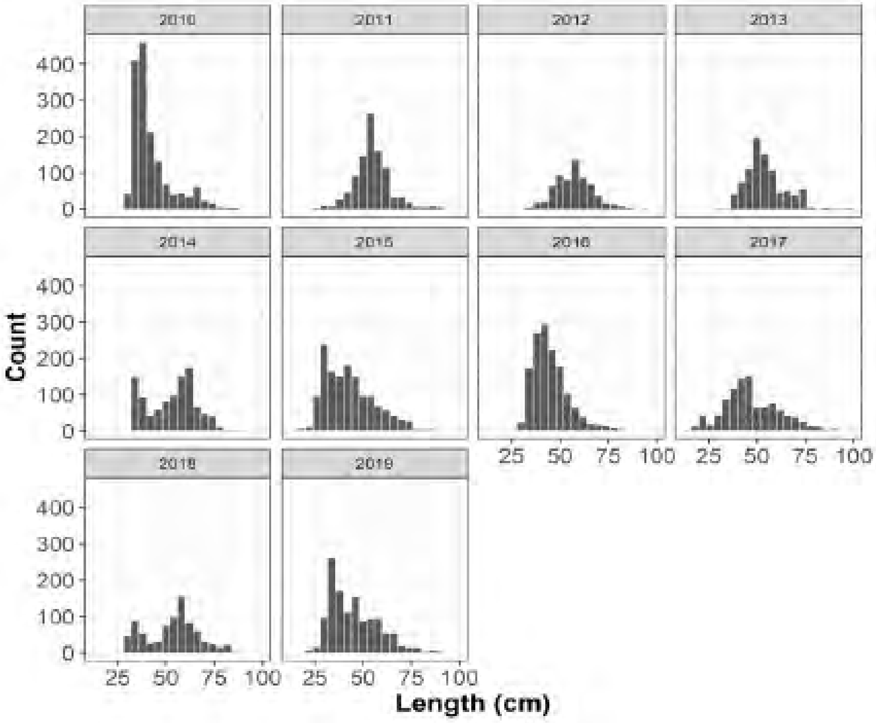

Figure 6.2. Annual length composition of commercial landings.

Scientific surveys

Pollack abundance indices resulted negligible or zero in the groundfish surveys developed in the distribution area: EVHOE, SP-NSGFS and PT-IBTS. The bottoms preferred for this species (wrecks and rocky bottoms) makes that trawl surveys are probably not very well suited for monitoring this species.

Commercial abundance index

A commercial abundance index for pollack for the French gillnet fleet in Division 8.a was provided to the WGBIE2019 for years 2005 to 2015 (Léauté *et al.*, 2018). The reference fleet was built using the information available in logbooks and it is constituted by trips selected based on the typology of the vessel and mesh size, and considering the spatial and temporal variability of the index. The index includes information for fishing sequences performed with gillnets of mesh size >= 90 mm and acting during the 2nd semester of the year in ICES Division 8a (FR-GN90-8a-2s). An update of the index was provided to the WGBIE2020 to cover the period 2016 to 2018 (Caill-Milly *et al.*, 2020). After the data compilation meeting of WKMSYSPiCT, the index was updated with the information for year 2019 and it was provided to the WKMSYSPiCT. The updated FR-GN90-8a-2s series for the period 2005–2019 is presented in Table 6.3.

The landings of the selected fleet represent an average of 7.4% of the total landings of the stock. Landings of this fleet have fluctuated between 77 t and 218 t recorded in 2006 and 2011, respectively. Since 2014, there is a decreasing trend in landings. The effort unit is the fishing sequence, a combination of vessel, gear, statistical rectangle, and day. After an increasing period, between 2011 and 2016, effort of FR-GN90-8a-2s has decreased in the last three years. The LPUE showed a decreasing trend from 2011 to 2018, declining from 218 Kg/Fs in 2011 to 105 Kg/Fs in 2018. In 2019, LPUE has increased to 141 Kg/Fs.

The size range of sampled landings of FR-GN90-8a-2s represents the length composition of the exploited population. The mean fork length of Pollack over the 15 years was 56 cm, and the size range was 30–97 cm.

Table 6.3. Commercial LPUE abundance index FR-GNS90-8a-2s, updated in 2020. Representativeness in percentage of the total stock landings is also indicated.

Year	Landings (Kg)	Fishing sequences (n)	LPUE (Kg/Fs)	% Stock Landings
2005	97484	829	118	4.9
2006	51794	669	77	2.4
2007	120701	895	135	6.5
2008	139003	1036	134	6.0
2009	104658	810	129	5.8
2010	81178	721	113	4.8
2011	142528	654	218	7.0
2012	149691	746	201	9.8
2013	148872	876	170	8.2
2014	171901	1045	164	8.8
2015	168819	1051	161	10.5
2016	147280	1275	116	8.9
2017	133351	1151	116	9.0
2018	112631	1071	105	7.4
2019	164852	1168	141	10.6

6.3 Stock assessment

The stock assessment was performed using the software SPiCT v1.3.3 (Pedersen and Berg, 2017) available at https://github.com/DTUAqua/spict.

Input data

The input data for the model were the time-series of commercial landings for years 1979–2019 and the commercial abundance index FR-GNS90-8a-2s for years 2005–2019 (Figure 6.3).

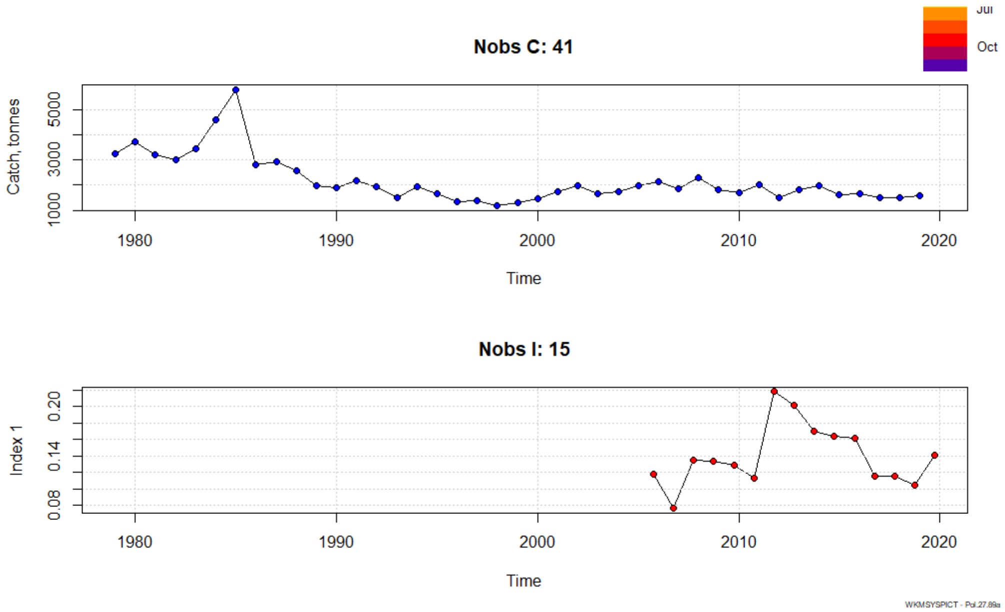

Figure 6.3. Input data for the SPiCT model.

Prior distributions

The Bayesian approach of the SPiCT can take account of prior information. Informative prior distributions were created to represent existing knowledge about the likely values of some model parameters. The intrinsic rate of growth parameter *r*, the initial depletion level (ratio of initial biomass to carrying capacity) *bkfrac* and the production curve parameter *n* had prior distributions.

Prior distribution of *r* was estimated based on knowledge of historical stock exploitation and the species biology. Two approaches were followed to obtained *r* priors. In the first approach the stock *r* parameter was generated from FishLife (Thorson, 2019) using Multivariate-Normal (MVN) Monte Carlo simulations and applying the function *flmvn_traits* available at the R-package SPMpriors (Winker, 2020). The results constructed *r* prior distribution of mean= 0.3494 and log.sd=0.37. In the second approach, the MVN *r* parameter from FishLife was translated into Pella-Tomlinson surplus production model prior of *r* through an age-structured equilibrium model. The function *fl2asem*, available in the SPMpriors library was used in this second approach. The *r* prior was set at mean= 0.23 and log.sd= 0.26.

The results of the meta-analyses carried out by Thorson *et al*. (2012) indicated prior distribution of *n* parameter for Gadiformes were n.est= 1.729 and sdn = 0.937 (log.sd=0.542). These values were also used in the exploratory assessment runs.

The long history of the pollack fishery, more than 80 years, the coastal distribution of the species and being an open-access resource, support that the biomass at the beginning of the time-series could be low in relation to K. Initially, two options of *bkfrac* prior distribution were considered: 1) mean=0.3 and log.sd=0.5 and 2) mean=0.5 and log.sd=0.2.

6.3.1 Exploratory assessments

To assess pollack, we considered two main scenarios based on the catch data time-series. The “scenarios 1” that use the period 1979–1983 and 1986–2019, allowing SPiCT to estimate the catch for years 1984 and 1985, and “scenarios 2” that use the whole time-series of catch data available (1979–2019) and increase the uncertainty of the catch for years 1984 and 1985 by factor=5 (sdevfC=5).

Multiple runs were built, based on the two scenarios and the elective use of informative priors for *r*, *bkfrac* and *n*. In addition, we ran two scenarios (1.4. and 1.5) with a very high *r* prior (mean=1.26, log.sd=0.26) to explore the impact of *r* prior distribution (Table 6.4).

Six of the eight "scenarios 2" reached the convergence. However, the model fits were considered not stable. They failed to converge with one year less of data and showed a high sensitivity to the change of starting values (Table 6.4). Probably, the extreme landing values for years 1984 and 1985 used as input of the model assessment, have a relevant impact on the robustness of the model. The perception of the stock in terms of relative biomass and fishing mortality changed between scenarios, finding totally opposed results (Table 6.5).

The "scenarios 1", with no landing data for years 1984 and 1985, needed to fix n=2 and/or to use very informative priors of *bkfrac* and *r* to achieve the convergence (Table 6.4). Of the ten scenarios 1 performed, only four achieved the convergence. The SPiCT diagnostics indicated that in all these scenarios had a violation of the normality of the residuals of catch (Shapiro-Wilk test, p-value < 0.05) (Figures 6.4 to 6.7). Scenarios 1.4 and 1.5, which assumed an unrealistic *r* prior value for this stock, achieved the convergence. Their retrospective analyses presented convergence problems for run-4 and run-3 (Figures 6.4, 6.5). The high value of *r* estimated by the model in these scenarios (r=1.14) would indicate a high resilience of the stock and would lead the model to estimate low values for the biomass reference point (3.5 kt) and extremely high F_{MSY} (0.56). The scenarios 1.4 and 1.5 were not considered credible, since their results are not consistent with the biology of the species. The model configuration of scenario 1.8 included fixing n=2, *r* prior distribution = log (0.35), 0.37, and a *bkfrac* prior = log (0.3), 0.5. With the exception of the Shapiro test for catch residuals, the SPiCT diagnostics and the starting values analysis indicated that model fit could be acceptable (Figure 6.6). Although the Mohn's rho values were < 0.2 and all retro trajectories were inside the credible intervals of the base run, the retrospective analysis seemed to indicate that there was a retrospective pattern. The scenario 1.10, which model configuration only differed from scenario 1.8 in the *bkfrac* prior, obtained similar results as scenario 1.8 (Table 6.5). The perception of the stock would be that the biomass is above the reference point (B_{2019}/B_{MSY}=1.35) and the fishing mortality is below F_{MSY} (F_{2019}/F_{MSY}=0.57). Also, the *r* value estimated by both scenarios was r=0.39, which would be expected for this species. The results from diagnostics analysis and retrospective analysis are not different from those of the scenario 1.8.

Table 6.4. Overview of the scenarios performed. Prior distributions, model convergence and results of SPiCT diagnostics.

Scenarios 1	priors			Convergence	Diagnostics	Retrospective	Starting values
	logn	logbkfrac	logr				
Scenario 1.1				no			
Scenario 1.2	n=2			no			
Scenario 1.3	n=2	log(0.5), 0.2		no			
Scenario 1.4	log(1.73), 0.54		log(1.26), 0.26	yes	OK, normalityC	OK (4 peels)	OK
Scenario 1.5	n=2		log(1.26), 0.26	yes	OK, normalityC	OK (3 peels)	OK
Scenario 1.6	n=2		log(0.23), 0.26	no			
Scenario 1.7	n=2		log(0.35), 0.37	no			
Scenario 1.8	n=2	log(0.3), 0.5	log(0.35), 0.37	yes	OK, normalityC	OK	OK
Scenario 1.9	n=2	log(0.3), 0.5		no			
Scenario 1.10	n=2	log(0.5), 0.3	log(0.35), 0.37	yes	OK, normalityC	OK	OK

Scenarios 2	priors			Convergence	Diagnostics	Retrospective	Starting values
	logn	logbkfrac	logr				
Scenario 2.1				yes	OK	Failed conv. All retros	
Scenario 2.2	n=2			no			
Scenario 2.3	n=2	log(0.5), 0.2		yes	OK	No, Inside CI, Mohn's > 0.2	2 local optima
Scenario 2.4	n=2	log(0.5), 0.2	log(0.23), 0.26	yes	OK	No, Inside CI, Monh's > 0.3	2 local optima
Scenario 2.5	n=2		log(0.35), 0.37	no			
Scenario 2.6	n=2	log(0.3), 0.5	log(0.35), 0.37	yes	OK	Failed conv. All retros	2 local optima
Scenario 2.7	n=2	log(0.3), 0.5		yes	OK	Failed conv. All retros	2 local optima
Scenario 2.8	n=2	log(0.5), 0.2	log(0.35), 0.37	yes	OK	Failed conv. All retros	2 local optima

Table 6.5. Model parameters estimates, reference points and stock status in the last year for all scenarios that converged.

	n: log(1.73), 0.54	n=2	n=2	n=2		n=2	n=2	n=2	n=2	n=2
			bkfrac: log(0.3), 0.5	bkfrac: log(0.5), 0.3		bkfrac: log(0.5), 0.2	bkfrac: log(0.3), 0.5	bkfrac: log(0.3), 0.5	bkfrac log(0.3), 0.5	bkfrac: log(0.5), 0.2
	r: log(1.26), 0.26	r: log(1.26), 0.26	r: log(0.35), 0.37	r: log(0.35), 0.37			r: log(0.23), 0.26	r: log(0.35), 0.37		r: log(0.35), 0.37
Model Parameters	**Scenario 1.4**	**Scenario 1.5**	**Scenario 1.8**	**Scenario 1.10**	**Scenario 2.1**	**Scenario 2.3**	**Scenario 2.4**	**Scenario 2.6**	**Scenario 2.7**	**Scenario 2.8**
alpha	0.82	0.82	1.57	1.71	3.83	3.36	3.06	2.67	3.26	2.85
beta	1.20	1.20	1.17	1.32	1.15	1.49	1.84	0.98	1.53	0.92
r	1.14	1.14	0.39	0.39	0.13	0.15	0.22	0.29	0.11	0.29
m	2088	2088	2231	2160	2147	2108	2213	2328	2474	2407
K	7316	7302	23078	22397	50802	55080	40077	31684	86221	32688
q	2.92E-05	2.930E-05	8.7E-06	8.96E-06	4.22E-06	7.04E-06	1.10E-05	6.39E-06	6.16E-06	6.14E-06
n	2.01	2	2.00	2.00	1.19	2	2	2	2	2.00
sdb	0.22	0.22	0.13	0.12	0.06	0.07	0.08	0.08	0.07	0.08
sdf	0.10	0.10	0.12	0.11	0.08	0.06	0.05	0.09	0.06	0.10
sdi	0.18	0.18	0.20	0.21	0.24	0.24	0.25	0.22	0.24	0.22
sdc	0.12	0.12	0.14	0.14	0.09	0.09	0.10	0.09	0.09	0.09
Reference Points (s)										
Bmsys	3510	3498	11243	10943	20169	27036	19710	15623	42010	16144
Fmsys	0.56	0.56	0.19	0.19	0.11	0.08	0.11	0.15	0.06	0.15
MSYs	1963	1962	2127	2071	2121	2034	2145	2268	2352	2352
States (s)										
B_2019.94	4651	4635	15175	14759	31387	18726	11869	21250	21132	22339
F_2019.94	0.35	0.35	0.1	0.11	0.05	0.08	0.13	0.07	0.07	0.07
B_2019.94/Bmsy	1.32	1.33	1.35	1.35	1.56	0.69	0.60	1.36	0.50	1.38
F_2019.94/Fmsy	0.63	0.63	0.55	0.57	0.47	1.11	1.22	0.51	1.32	0.48

The results of these exploratory SPiCT assessments suggested that the model does not have enough information to estimate all parameters of the model. This is likely a result of the short time-series of the abundance index (15 years) and the lack of contrast in catch series in the overlapping period catch-cpue. The systematic deviations in the retrospective analyses for scenarios 1.8 and 1.10 did not offer enough confidence in the predictive capabilities of these model assessments. Therefore, none of the scenarios performed were considered robust enough to be accepted for assessing and forecasting the stock.

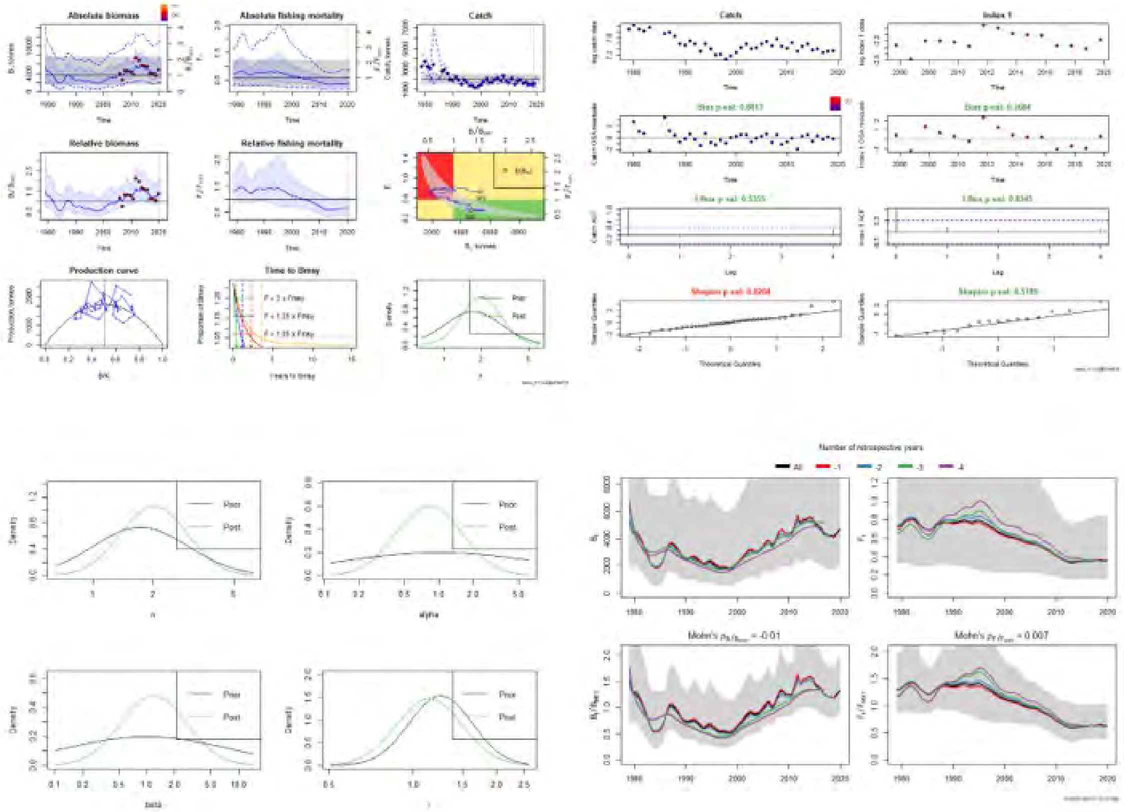

Figure 6.4. Scenario 1.4. Top-left: Model results; Top-right: diagnostics; Bottom-left: priors and posteriors; Bottom-right: retrospective analysis (4 peels).

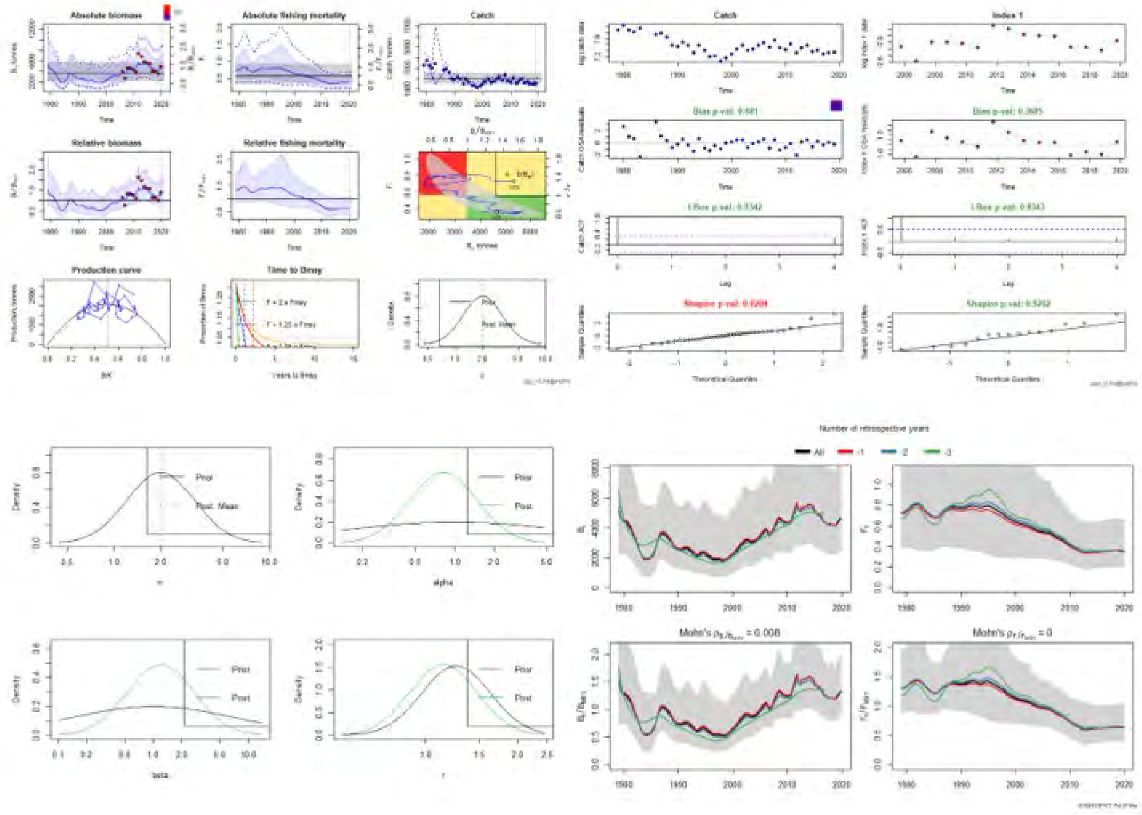

Figure 6.5. Scenario 1.5. Top-left: Model results; Top-right: diagnostics; Bottom-left: priors and posteriors; Bottom-right: retrospective analysis (3 peels).

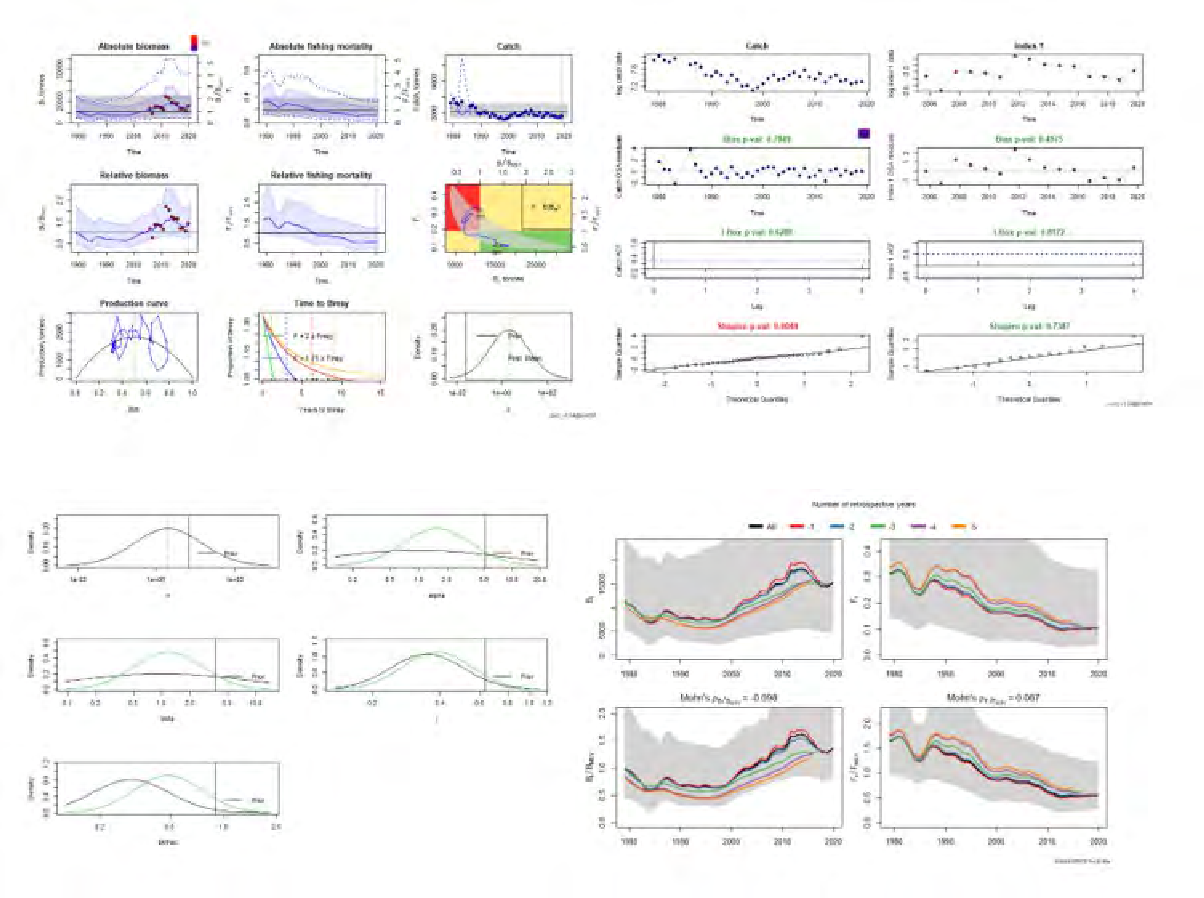

Figure 6.6. Scenario 1.8. Top-left: Model results; Top-right: diagnostics; Bottom-left: priors and posteriors; Bottom-right: retrospective analysis.

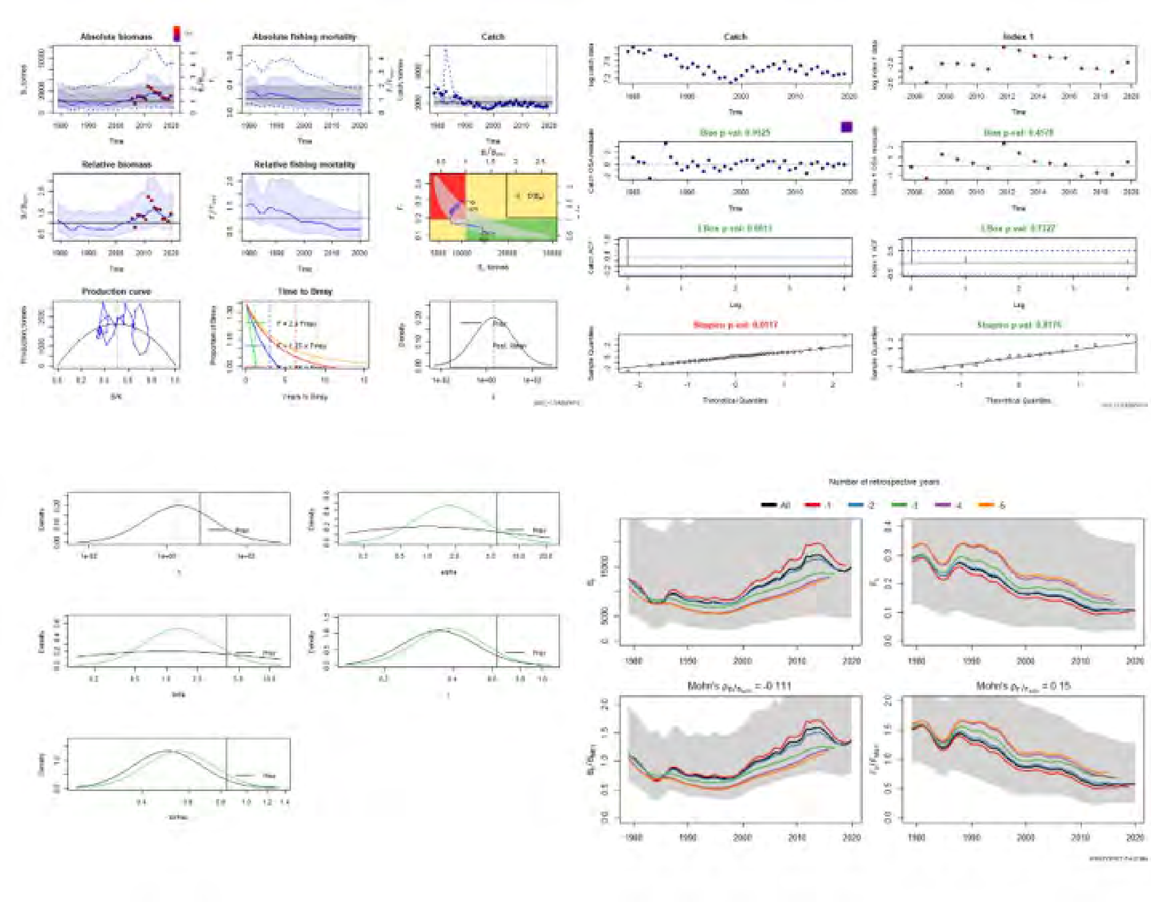

Figure 6.7. Scenario 1.10. Top-left: Model results; Top-right: diagnostics; Bottom-left: priors and posteriors; Bottom-right: retrospective analysis.

6.3.2 Final assessment

No model configuration was accepted by the Workshop to use as final model assessment.

6.4 Future considerations/recommendations

Integrated assessment models could be explored as key biological information and length composition of landings for some years are available for this stock.

It is recommended to standardize the commercial abundance index using alternative standardization methodologies.

6.5 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

The assessment of pollack in the Bay of Biscay and Iberian waters (8 and 9a) is based on a catch time-series from 1979 to 2019 and a commercial LPUE from 2005 to 2019 for the French gillnet fleet in Division 8a. The fishery for pollack has started far before 1979 with large catches in several periods before the 1970s. Although catches before 1985 are considered more uncertain, the catch time-series presented peaked in 1979, which is indication that the fishery started earlier than the 1970s. Pollack is a coastal, rather stationary predator species, which is fished by several gears, mostly passive. It is known to be prone to overexploitation as shown by Cardinale *et al*. (2011) for the Kattegat-Skagerrak area where is depleted since the 1980s and has never recovered.

The approach for computing the LPUE index is described in Léauté *et al*. (2018). This approach is broadly based on averaged catch rates for a selected cluster of catch records, which was derived by way of hierarchical clustering. Importantly, this approach was designed to characterize the catch rates for a number of reference fleets clusters, but not to derive standardized indices of abundance for input in a stock assessment model. Although somewhat similar clustering approaches can form the basis to account for targeting effects, this would require a different treatment of the response variable in the cluster analysis. If the aim is to identify clusters of fishing tactics for use as factorial variables in the standardization models, such as GLMs/GAMs, then the information about the magnitude of the catch rates (CPUE) has to be removed, which is typical achieved by using the square root transformations of the catch composition data (species proportions of catches) or similar. However, Léauté *et al*. (2018) applied a sequence of subsetting and clustering approaches to group the response variable catch rates (landings per trip) according to factors, including mesh size, vessel characteristics, statistical rectangle, year and month, which was followed by applying selection criteria to identify the highest performing clusters in terms of catch rates for the target species under assessment. This approach was considered problematic for the purpose of CPUE standardization, because (1) an annual change in stock abundance may be disguised as a result of catch rates falling, e.g., below a threshold may simply be excluded from a cluster in that year and (2) the selected cluster may only represent small temporal and spatial representation of the stock with much valuable information in the data being removed from the CPUE computation.

Some of the SPiCT model configurations tested estimate stock levels well above B_{MSY} in the first year (b/k around 1.5), which is not supported by the history of the catches. The model configurations tested also show generally retrospective pattern and/or autocorrelated residuals. Moreover, the r estimated for those runs were much higher than the prior for the species (i.e. around 1, the prior being 0.38).

The analysists provided additional runs using priors on r derived from the SPMpriors R package (https://github.com/Henning-Winker/SPMpriors) for deriving Schaefer and Pella-Tomlinson from FishLife (Thorson, 2020) through a MVN Age-Structured Monte-Carlo simulation approach and assuming a lower b/k ratio in the initial year. The results from alternative model configuration are highly sensitive to the prior specifications as the data contain little to no information on key parameters. This must be attributed to a quite short (15 years) CPUE time-series without a clear trend in combination with fairly flat catches in the overlapping period. Production models are most likely to work well when there have been periods of low and high exploitation in the period, where both CPUE and catch data are available. This is clearly not the case for this stock. The CPUE time-series covered a quite variable percentage of the total landings (Table 6.3), which may indicate that some years may be considerably more uncertain than others. Variance estimates from the standardization procedure for the CPUE time-series were not presented, which should be considered in the future.

Conclusions

Given the available data the only way to obtain a reasonable result is to use very strong priors. For this reason, we consider the presented SPiCT assessments not suitable for giving advice at this stage. More work should be done in future to improve the input data in terms of both the historical catches and the development of a model-based CPUE standardization approach that can account of targeting.

Moreover, the WDROMELIGO contains extensive data on size structure of the catches, discards, surveys and key biological parameters that could be used to develop a size-based model integrated assessment as an alternative to SPM in the future. Therefore, we suggest that the stock remains in category 3 with the trend informed by the fully standardized commercial CPUE (see section above) until an assessment model is developed.

6.6 References

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7 Norway lobster (*Nephrops norvegicuss*) in Division 9.a, Functional Units 28-29 (Atlantic Iberian waters East and southwestern and southern Portugal) (nep.fu.2829)

7.1 Introduction

The Norway lobster (*Nephrops norvegicus*) is distributed along the continental slope off the southwest (FU 28) and south (FU 29) Portuguese coast, at depths ranging from 200 to 800 m. Its distribution is limited to muddy sediments with 10–100% silt and clay content, required to excavate burrows (Bell *et al*., 2013).

The area of distribution of Norway lobster in these FUs, includes ICES rectangles 03E, 04E0 and 05E0 in FU 28 and rectangles 02E0, 02E1, 02E2 and 01E2 in FU 29 (Figure 7.1). Although FUs 28 and 29 are different stocklets, landing records are not differentiated by FU and are assessed together.

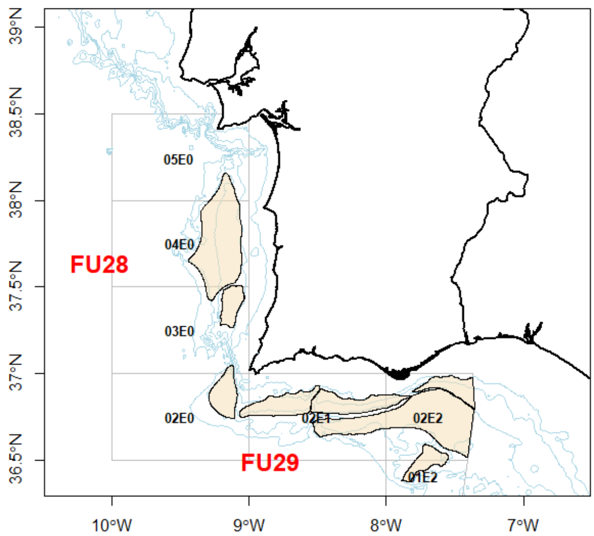

Figure 7.12. *Nephrops* in FUs 28–29 (SW and S Portugal). Fishing grounds overlaying ICES statistical rectangles.

7.1.1 The fishery

Norway lobster is a very valuable and important resource for the demersal trawl fisheries operating in the region. Together with the deep-water rose shrimp (*Parapenaeus longirostris*), Norway lobster constitutes the main target species of the majority of the crustacean trawl fleet. These two species have a different but overlapping depth distribution: the deep-water rose shrimp occurs at the depth range of 100–350 meters whereas Norway lobster is distributed from 200–800 meters. Depending on their abundance/availability, the effort is mostly directed at one species or the other (Figure 7.2) i.e. years with lower catches of *Nephrops* are mostly related to peaks of abundance of deep-water rose shrimp, which is caught near shore and at with lower fishing costs.

In what concerns the distribution of the fishing effort between the two Functional Units, FU29 represents in average 83% of the total effort.

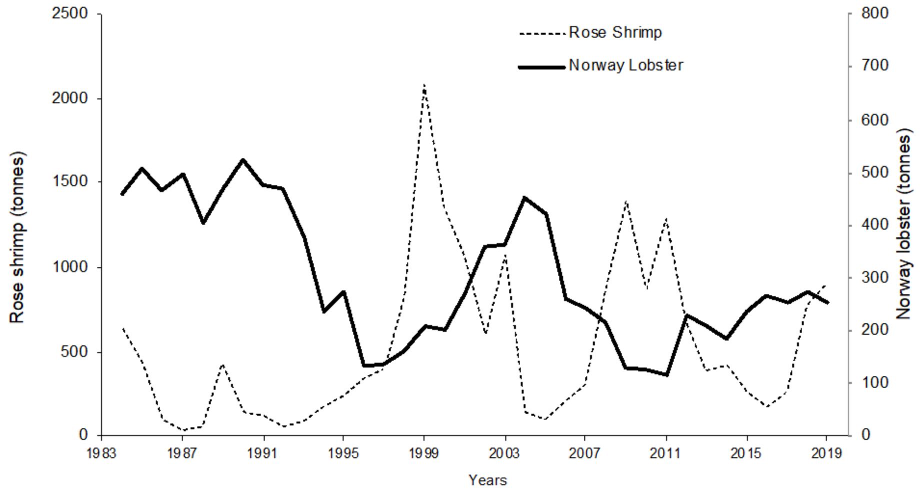

Figure 7.13. *Nephrops* in FU 28–29. Landings (in tonnes) of the two main target species of the Crustacean Fishery in the period 1984–2019.

The Portuguese trawl fleet comprises two components, namely the trawl fleet targeting demersal fish and the trawl fleet targeting crustaceans. The trawl fleet targeting demersal fish operates off the entire Portuguese coast, while the trawl fleet directed to crustaceans operates mainly in Southwest and South Portugal and at deeper waters (≥ 200 m), where the crustacean species are more abundant. The fish trawlers are licensed to use a mesh size ≥ 65 mm and the crustacean trawlers are licensed for two different mesh sizes, 55 mm for catching shrimp and ≥ 70 mm for Norway lobster.

The number of trawlers targeting crustaceans has been fixed at 35 since the early 1990s. However, in late 1990s, some vessels have been replaced by new ones, better equipped and more powerful, and the number of crustacean trawlers was then reduced to 30. In the last decade (2010s), the fishery in FUs 28 and 29 was mostly conducted by the Portuguese crustacean fleet composed by an average of 23 vessels (18–29 m of overall length and 220–450 kW) and up to five Spanish trawlers licensed for this fishery under a bilateral agreement.

The fishery takes place throughout the year, with the highest landings usually being made in spring and summer. The main bycatch species are blue whiting, hake and anglerfish (Abad *et al.*, 2007).

7.1.2 Current assessment and advice

Nephrops in FUs 28–29 is currently in stock category 3.2. The stock status is assessed with methods for Data-Limited Stocks (DLS), namely Length-Based Indicators (LBI) and Mean Length Z (ICES, 2015), using the landings length composition for males and females since 1984 (ICES, 2020). The advice is biennial and based on trends of the standardized CPUE, adopted as an index of stock indicator (ICES, 2019).

A discontinuous survey series, available for the period 1997–2018, is used as auxiliary information.

Although not possible to be used in the SPiCT model, the available length information could be informative for the development of new integrated assessment models.

7.1.3 Management applied to this fishery

A recovery plan for southern hake and Iberian *Nephrops* stocks was enforced since the end of January 2006 (Council Regulation (EC) No 2166/2005-EU, 2006). This recovery plan included a reduction of 10% in the hake F relative to the previous year and TAC set accordingly, within the limits of ±15% of the previous year TAC. Although no clear targets were defined for Norway lobster stocks in the plan, the same 10% reduction was applied to these stocks TAC. The recovery plan target and rules were not changed since its implementation. Although not revoked, the enforcement of the plan was relaxed in 2017–2018 and, in March 2019, a new multiannual plan for stocks fished in the Western Waters (including the *Nephrops* stocks in these FUs) and adjacent waters was established (European Parliament and Council Regulation (EU) No 2019/472-EU, 2019a), repealing the previous recovery plan. In the current Management Plan for Western Waters, applied to 2020 onwards, no effort limitations were established.

Besides the recovery plan, the CR (EC) No 2166/2005 also amended the CR (EC) No 850/98 (EU, 1998) introducing two boxes in Division 9.a, one of them located in FU 28. In the period of higher catches (May–August), this box is closed for *Nephrops* fishing. By derogation, fishing with bottom trawls in this area and period is authorised if the bycatch of Norway lobster does not exceed 2% of the total weight of the catch. The same applies to creels that do not catch *Nephrops*. After the repeal of CR (EC) No 850/98, these restricted areas were included in the Regulation (EU) 2019/1241 of the European Parliament and of the Council (EU, 2019b), establishing technical measures on the conservation of fisheries resources and the protection of marine ecosystems.

With the aim of reducing effort on crustacean stocks, a Portuguese national regulation (Portaria no. 1142, 13th September 2004) closed the crustacean fishery in January–February 2005 and enforced a ban in *Nephrops* fishing for 30 days in September–October 2005, in FUs 28–29. This regulation was revoked in January 2006, after the entry in force of the recovery plan and the amendment to the Council Regulation (EC) No 850/98, keeping only one month of closure of the crustacean fishery in January (Portaria no. 43/2006, of 12th January 2006). This period was extended to February in 2016 (Portaria no. 8-A/2016, of 28th January 2016), for this year only. The national regulations are only applicable to the Portuguese fleet.

Portugal and Spain have bilateral agreements for fishing in each other waters. Under this agreement a number of Spanish trawlers are licensed to fish crustaceans in Portuguese waters. No information from landings of these vessels is available for the years prior to 2011.

Unwanted catches from *Nephrops* are regulated by the discard plan for demersal fisheries in southwestern waters for the period 2019–2021 (Council Regulations (EC) No 2018/2033 and 2019/2237-EU, 2018, 2019c), under which they are exempted from the landing obligation based on the species high survival rates. This exemption applies to all catches of Norway lobster from ICES subareas 8 and 9 with bottom trawls, and all discards shall be released, immediately and in the area where they were caught.

The minimum landing size (MLS) for *Nephrops norvegicus* is 20 mm of carapace length (CL) or 70 mm of total length (TL).

7.2 Input data for stock assessment (ToR 1 & 2)

7.2.1 Landings and Discards

The available *Nephrops* landings information for the operation in FUs 28–29 by the Portuguese and Spanish fleets during the period 1975–2019, are summarized in Table 7.1. The landings reported between 1975 and 1982 are of higher magnitude and have some associated uncertainty (i.e. during that period Spain reported around 1600 ton, and after that, no landings were reported until 2011).

According to Cadima *et al.* (1995), from 1975 to 1982 the total catches in Alentejo (FU 28) and Algarve (FU 29) were made mainly by the Spanish trawl fleet, with average catches of around 100 t and 1500 t, respectively. From 1983 to 2011, no Spanish catches were reported. There will be, probably, unreported catches since by the 1978 agreement the Spanish trawl fleet was allowed to operate only beyond the 12-mile zone where most of *Nephrops* grounds are located.

Discards are considered negligible, based on the results obtained from the DCF discard sampling programme onboard the Portuguese crustacean trawlers, since 2004. When occurring, discards of *Nephrops* are not related to size but mainly related to quality (i.e. broken or soft shells).

7.2.2 Standardized commercial CPUE and effort

The standardized commercial CPUE series used in the most recent advices was presented to Inter-benchmark Protocol for *Nephrops* in 2012 (ICES, 2012), updated and improved in the following years (e.g. ICES, 2020). The commercial CPUE series was standardized using generalized linear models (GLMs) and built with positive records of Norway lobster, based on the assumption that this is a target fishery. In the WKMSYSPiCT data evaluation workshop held in November 2020, a new approach for the standardization of the CPUE series was presented, including both positive and null catches. Some recommendations made by the reviewers were incorporated in the final model, namely related to the variables used to mimic the target fishing, as the proportion of *Nephrops* which is not truly independent from the response variable, and the use of vessels as random effect.

The data used for this standardization were the crustacean trawlers logbooks and the VMS records for the period 1998–2019. With the aim of finding the best model to explain the behaviour of *Nephrops* CPUE, several formulations were tested considering the following explanatory variables and approaches:

- **Year** was tested with two different time periods:

  Option 1: 1998–2019;

  Option 2: 2001–2019, i.e. removing the years in the beginning of the series, with lower number of records.

- **Month** as a factor with 12 levels.
- A new variable was included in the model, the **fishing ground**, to take into account the spatial dimension of the *Nephrops* distribution. Eight levels were considered in this factor, defined by the spatial polygons represented in Figure 7.1, which includes two fishing grounds in FU28 and 6 in FU29.
- **Depth** was included in the models with two different approaches:

  Option 1: using depth intervals: [100, 200[, [200, 400[, [400, 600[, 600, 800[, [800, 1600] m.

  Option 2: using depth as a continuous variable but transformed with multiple fractional polynomials (MFP) using the '*mfp*' package (Benner, 2015), as linear models assume explanatory variables to be linearly associated with the response variable, and depth has a non-linear behaviour. The MFP which best predicted the depth variable was: I((depth/1000)^2)+I((depth/1000)^3);

  Option 3: using depth as a continuous variable with a smooth function (only applied in GAMs).

- To identify **clusters of target fishing**, a non-hierarchical clustering technique, CLARA (Kaufman and Rousseeuw, 1990; Struyf *et al*., 1996), was applied to the catch composition matrix, using the '*cluster*' package (Maechler *et al*., 2019). The matrix contained the proportion in weight per hour of the five main crustacean species caught by the fishery in each record in relation to the total weight per hour of crustaceans. The species considered were: Norway lobster, deep-water rose shrimp, blue and red shrimp (*Aristeus antennatus*), giant red shrimp (*Aristaeomorpha foliacea*) and scarlet shrimp (*Plesiopenaeus edwardsianus*). The CLARA analysis was based on 100 data samples, each comprising 1000 records. The optimal number of '*k*' clusters was selected by iterative maximization of the 'Average Silhouette Width' (ASW). Although the highest ASW was obtained for k=two clusters (ASW=0.62), it was discussed that this could be limitative to describe the target fishing, so that the scenario using k=4, the second largest value obtained (ASW=0.57), was also considered. For the scenario k=2 the characterization by cluster with the species proportion by year (Figure 7.3) led to identify one cluster (cluster 2) with a high proportion of deep-water rose shrimp (95%) and the other (cluster 1) with a higher diversity of species, being *Nephrops* the dominant one (67%). For the scenario k=4, apart from the deep-water rose shrimp cluster (100%, cluster 3), one can be considered a *Nephrops* cluster (86%, cluster 4), another with a mixture of those two main species but with higher proportion of deep-water rose shrimp (66%, cluster 1) and a fourth one (cluster 2) containing more deep-water species like blue and red shrimp (56%) and scarlet shrimp (11%). The different depth ranges explored in each cluster seem to be better explained in the k=4 scenario and result on a better segregation of the target species.
- **Vessel** (*cfr*) was included in the models with three different approaches:

  <u>Option 1</u>: considering all 44 different vessels as factor levels;

  <u>Option 2</u>: grouped in three categories: A (standard), B and C. These two categories correspond to vessels less or more productive than the standard type;

  <u>Option 3</u>: included as random effects.

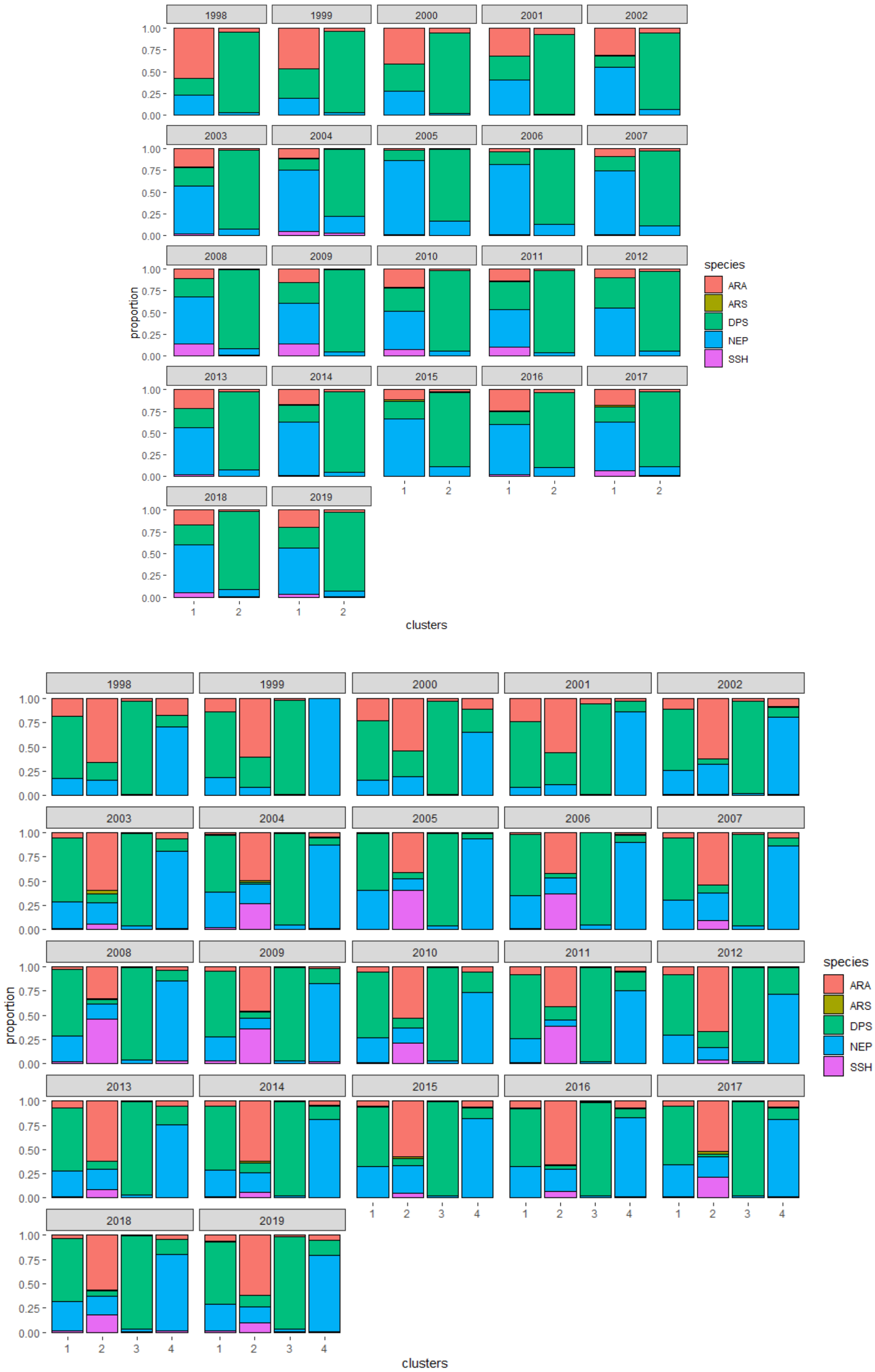

Figure 7.3. ***Nephrops*** **in FU 28–29. Proportion in weight of the five crustacean species by cluster, considering two clusters (upper panel), and four clusters (lower panel). ARA: blue and red shrimp (*Aristeus antennatus*), ARS: giant red shrimp (*Aristaeomorpha foliacea*), DPS: deep-water rose shrimp (*Parapenaeus longirostris*), NEP: Norway lobster (*Nephrops norvegicus*), SSH: scarlet shrimp (*Plesiopenaeus edwardsianus*).**

In order to find the best model to describe the annual trend of *Nephrops* commercial CPUE in FU 28–29, different types of models were applied: GLMs, Generalized Linear Mixed Models (GLMM) and Generalized Additive Models (GAM). For all the tested models, given that the response variable is a continuous variable with a discrete mass at 0, a Tweedie distribution with a log-link function was assumed. The best model was selected based on the explained deviance, the Akaike information criterion (AIC) and residual diagnostics. The mean estimates of the standardized CPUE series of *Nephrops* from each model were obtained with the least-squares means (Lenth, 2016).

All tested variables were significant and included in the final model. Removing the years with more uncertainty due to the lower number of records (i.e. removing 1998–2000) did not improve the models. Concerning the depth options, the model performance was better when using the transformed variable instead of classes, yet when testing the GAM models, better results were achieved when applying a smooth function, as GAM can accommodate variables with nonlinear behaviour. When testing the use of two or four clusters to define the target fishing, the results were significantly improved when using the latter. In summary, the best model selected was a GAM with year, month, fishing ground, depth with a smooth function and target fishing defined by four clusters as fixed terms and vessel as a random effect (59.6% explained deviance). The residual diagnostics and the comparison between the standardized and the nominal CPUE are presented in Figures 7.4 and 7.5, respectively.

Standardized effort in trawling hours is estimated based on this modelled series, dividing the total catch by the standardized CPUE. The standardized CPUE annual values and the corresponding estimated effort values are presented in the summary Table 7.2.

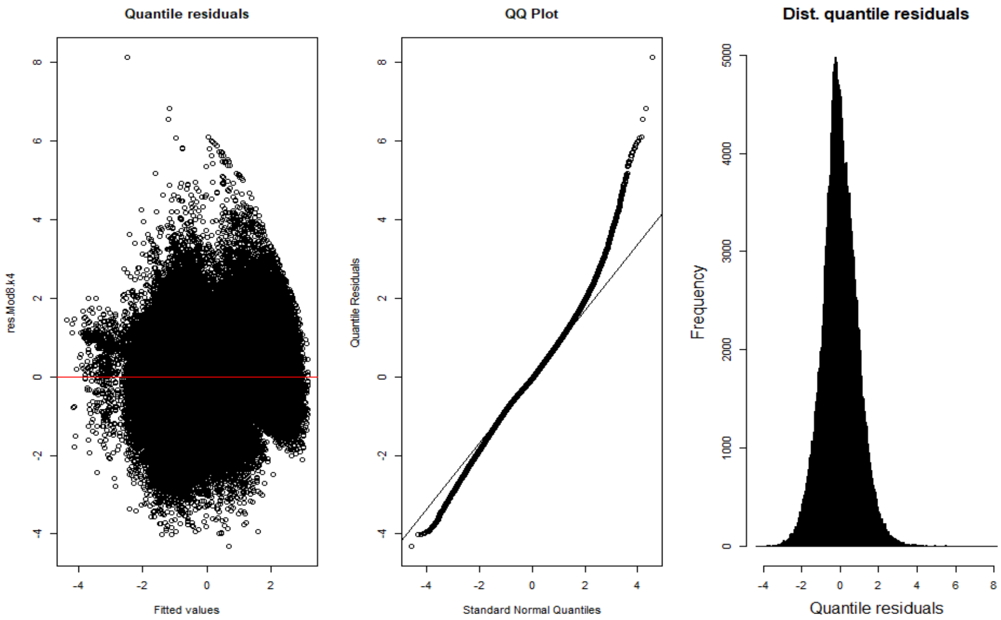

Figure 7.4. *Nephrops* in FUs 28–29. CPUE standardization model, residuals plots, from the selected model.

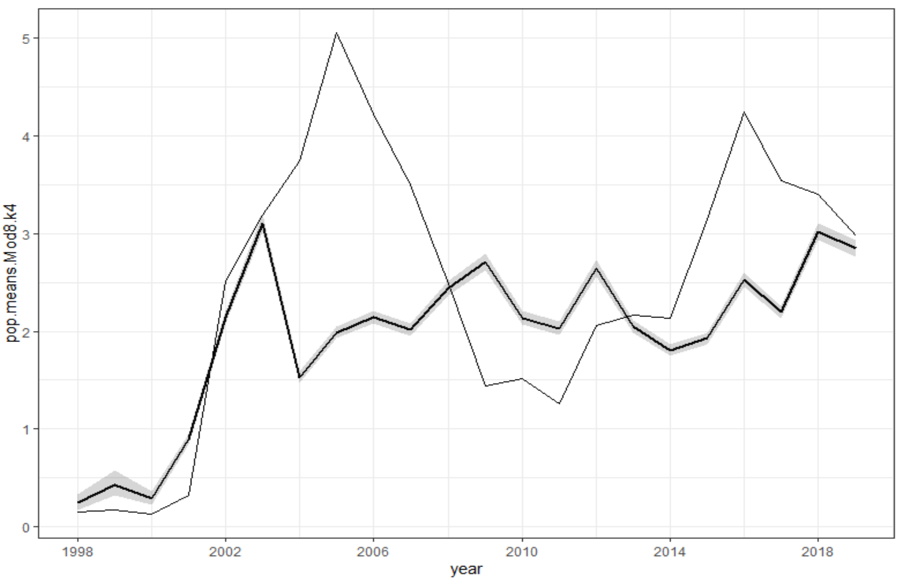

Figure 7.5. *Nephrops* in FU 28-29. Comparison of standardized CPUE from the selected model (thicker line with confidence intervals shaded in grey) and nominal CPUE (thinner line), considering both zero and positive catches of *Nephrops*.

7.2.3 Surveys

The Portuguese three-week crustaceans trawl survey is conducted every year in May–July (NepS (FU 28–29)), in the period when males and females are at their maximum activity, out of the burrows and both sexes available to the trawl gear. The design of the survey is described in ICES (2018) and Silva *et al.* (2019). The survey, covering the whole area, started in 1997. There are some missing values in some of the years, due to different problems. The series was disrupted in 2019 and will be re-started with a different vessel.

Figure 7.6 shows the time-series of the estimated biomass indices for deep-water rose shrimp and Norway lobster (Silva *et al.*, 2019). The biomass index values for Norway lobster are presented in the summary Table 7.2.

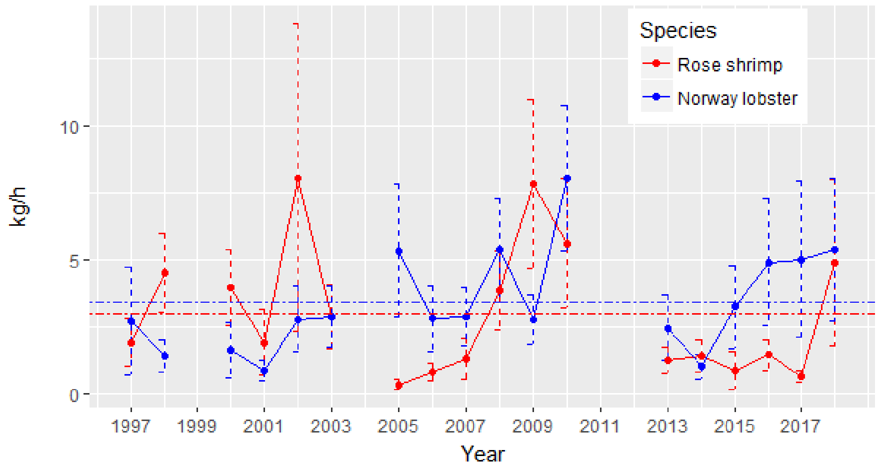

Figure 7.6. Stratified mean biomass index time-series with 95% confidence interval for Norway lobster and deep-water rose shrimp in FU 28–29.

Table 7.1. *Nephrops* landings time-series from FUs 28–29, by Portuguese and Spanish fleets.

	Spain		Portugal			Total
	28***	29	28 + 29			
Year	Trawl	Trawl	Artisanal	Trawl	Total	
1975	137	1510		34	34	1681
1976	132	1752		30	30	1914
1977	95	1764		15	15	1874
1978	120	1979		45	45	2144
1979	96	1532		102	102	1730
1980	193	1300		147	147	1640
1981	270	1033		128	128	1431
1982	130	1177		86	86	1393
1983				244	244	244
1984				461	461	461
1985				509	509	509
1986				465	465	465
1987			11	498	509	509
1988			15	405	420	420
1989			6	463	469	469
1990			4	520	524	524
1991			5	473	478	478
1992			1	469	470	470
1993			1	376	377	377
1994				237	237	237
1995			1	272	273	273
1996			4	128	132	132
1997			2	134	136	136
1998			2	159	161	161
1999			5	206	211	211
2000			4	197	201	201
2001			2	269	271	271

	Spain		Portugal			Total
	28***	29	28 + 29			
Year	Trawl	Trawl	Artisanal	Trawl	Total	
2002			1	358	359	359
2003			35	335	370	370
2004			31	345	375	375
2005			31	360	391	391
2006			17	274	291	291
2007			18	274	291	291
2008			35	188	223	223
2009			17	133	151	151
2010			16	131	147	147
2011		17	16	117	133	150
2012		14	3	211	214	229
2013		10	1	198	199	209
2014		8	3	183	186	193
2015		12	4	231	235	247
2016		21	8	254	262	283
2017		26	9	241	249	275
2018		25	10	263	273	299
2019**		31	8	245	253	284

**** Preliminary values.**

***** Spanish landings from FU28 included in FU29.**

Table 7.2. *Nephrops* FU 28–29. Landings, effort and biomass indices.

Year	Total Landings (t)	Standardized Trawl Effort (hours)	Std CPUE (kg/h) (new model)	Crustacean Survey CPUE (kg/h)
1975*	1681			
1976*	1914			
1977*	1874			
1978*	2144			
1979*	1730			
1980*	1640			
1981*	1431			
1982*	1393			
1983*	244			
1984	461			
1985	509			
1986	465			
1987	509			
1988	420			
1989	469			
1990	524			
1991	478			
1992	470			
1993	377			
1994	237			
1995	273			
1996	132			
1997	136			2.683
1998	161	663,870	0.243	1.404
1999	211	493,740	0.427	
2000	201	695,442	0.289	1.617
2001	271	303,189	0.894	0.847
2002	359	167,420	2.144	2.763

Year	Total Landings (t)	Standardized Trawl Effort (hours)	Std CPUE (kg/h) (new model)	Crustacean Survey CPUE (kg/h)
2003	370	119,055	3.108	2.854
2004	375	245,106	1.530	
2005	391	196,586	1.989	5.336
2006	291	135,792	2.143	2.789
2007	291	144,343	2.016	2.859
2008	223	91,137	2.447	5.350
2009	151	55,716	2.710	2.769
2010	147	68,833	2.136	8.059
2011	150	73,804	2.032	
2012	229	86,711	2.641	
2013	209	101,879	2.051	2.459
2014	193	106,824	1.807	1.003
2015	247	128,154	1.927	3.236
2016	283	111,824	2.531	4.895
2017	275	125,228	2.196	4.961
2018	299	99,140	3.016	5.042
2019	284	99,619	2.851	

*** Uncertain Landings.**

ns No survey.

(a) Survey with a different vessel.

(b) Survey did not cover the whole area.

7.3 Stock assessment (ToR 3)

7.3.1 Exploratory assessments

The analyses were made with R version 3.6.3 (R Core Team, 2020) and the package SPiCT version 1.3.4 (Pedersen and Berg, 2017), following the Handbook and Guidelines developed for this package (Pedersen *et al*., 2020; Mildenberger *et al*., 2020).

In the exploratory runs two periods for the total catches were considered, 1975–2019 and 1984–2019, taking into account the high uncertainty in the reported catches prior to 1984. The biomass indices and effort series included in the explored SPiCT runs were the following:

i. one single biomass index (the survey index or the standardized CPUE index);
ii. the effort series;

iii. both biomass indices; and
iv. the survey index and the estimated standardized effort.

The settings considered in the exploratory runs included one or more of the following:

- initial prior for n set as 2, corresponding to the Schaeffer model (included in all runs);
- initial prior for α set as 1 (included in all runs);
- initial prior for β set as 1 (included in all runs);
- uncertainty added to the catches prior to 1993 (included in all runs, except those applying a robust estimation scheme to reduce influence of extreme observations);
- uncertainty added to the survey index in years 2010 and 2014, which were extreme values (included in all runs);
- uncertainty added to the years 1998–2001 of the CPUE series, which were based in less data records; alternatively, removing those years from the CPUE series;
- initial prior for *r* set as 0.15–0.2 (approximate value for the species, estimated with Leslie matrix);
- initial prior for *B*/*K* set as 0.2–0.5 (for some of the runs), taken into account the high exploitation levels before the beginning of the series;
- Initial prior for the standard deviation of fishing mortality process error (σ_F or *sdf*) set as 0.4.

In overall, the most relevant runs were those including a longer catch series (1975–2019) and a combination of two biomass indices or a combination of effort and survey index, as they provide the most complete set of available data to assess the status of the *Nephrops* FU 28–29 stock. Yet, it was also recommended to proceed with the runs removing the first four years of the standardized commercial CPUE as those were very low, as a consequence of either biased information provided by low number of logbook records and/or because these were years of high abundance of deep-water rose shrimp with a significant reduction of the effort targeting *Nephrops*; the same applies when the effort series was used. As the initial depletion level was assumed to be higher before the beginning of the available data, the use of a prior for *B*/*K* was advised, although some runs were presented in the meeting without it.

The input series, priors and results from the most relevant runs are summarized in Tables 7.3 and 7.4 and the main outputs presented in Figures 7.7 to 7.12. The selected runs included a higher uncertainty in the catches before 1984, scaled by a factor 3. Run 1 considered the shorter catch series (1984–2019) for comparison, with a stronger prior for *B*/*K* (*B*/*K=0.3*) and a prior for *r*. In run 2, only the base priors for *n*, α and β were applied. Runs 3-5 were performed applying sequentially and cumulatively a prior for *B*/*K* (run 3, with better results when *B*/*K=0.5*), then a prior for *r* (run 4, with better results when *r=0.2*) and a prior for *sdf* (run 5). Although, the last two runs provided the best fit (only with slight normality issues in the catch) the outputs from the two models were contradictory. While in run 4 (and also in runs 2 and 3) an overall scenario of overexploitation is obtained (biomass levels much below B_{MSY} and fishing mortality above F_{MSY} in most of the series and around this reference level in recent years), when a prior for *sdf* is applied in run 5, the perception changes showing a good stock status since the early 2000s (with an increasing trend in biomass and above B_{MSY} and fishing mortality below F_{MSY} since the early 1980s). The same contradictory results were obtained in runs with a combination of effort and survey data.

Table 7.3. Summary of selected SPiCT exploratory runs: Input series, diagnostics and results.

	Std CPUE + Survey Index					Std Effort + SurveyInd
	1	2	3	4	5	
Input series						
C	1984-2019	1975-2019	1975-2019	1975-2019	1975-2019	1975-2019
E (C/I1)						
I1 (std CPUE)	2002-2019	2002-2019	2002-2019	2002-2019	2002-2019	2002-2019
I2 (survey)	1997-2019	1997-2019	1997-2019	1997-2019	1997-2019	1997-2019
Increased uncertainty						
C periods:						
1975-1983		3	3	3	3	3
1984-1992	2					
E (C/I1)						
I1 (std CPUE)						
I2 (survey) - Years 2010 & 2014	2	2	2	2	2	2
Priors						
logn	2	2	2	2	2	2
logalpha	1	1	1	1	1	1
logbeta	1	1	1	1	1	1
logsdf					0.4	
logbkfrac	0.3		0.5	0.5	0.5	0.5
logr	0.2			0.2	0.2	0.2
Checklist for acceptance						
1. Convergence	✓	✓	✓	✓	✓	✓
2. Finite parameters	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
3. Violation of model assumptions						
shapiro	C*	C**	C**	C**	C***	C**
bias	✓	✓	✓	✓	✓	✓
acf	✓	✓	✓	I2.	✓	✓
LBox	✓	✓	✓	✓	✓	✓
4. Retrospective pattern	✓	✓	✓(-4)	✓	✓	✓
Mohn's Rho						
F/Fmsy	0.1416	-0.1964	0.0387	0.0899	-0.0412	0.0942
B/Bmsy	-0.1074	0.1150	-0.0298	-0.0717	0.0227	-0.0792
5. Realistic production curve	✓	✓	✓	✓	✓	✓
6. Assessment uncertainty	✓	×	✓	✓	✓	✓
7. Initial values sensitivity	✓	✓	✓	✓	✓	✓
Model Results						
K	9094	14336	27689	20345	21644	20533
r	0.20	0.15	0.11	0.18	0.21	0.18
q1	0.00070	0.00025	0.00052	0.00081	0.00013	
q2	0.00104	0.00037	0.00077	0.00120	0.00019	0.00114
qf						0.0000008
B_{2019}	4060	11224	5450	3559	21249	3796
B_{2019}/B_{MSY}	1.04	1.88	0.50	0.40	2.22	0.43
B_{MSY}	3893	5977	10954	8940	9560	8843
F_{2019}	0.07	0.03	0.05	0.08	0.01	0.08
F_{2019}/F_{MSY}	0.69	0.32	1.05	1.05	0.12	0.99
F_{MSY}	0.10	0.08	0.05	0.08	0.11	0.08
MSY	395	463	535	687	1040	667

Note: In red are indicated the series with problems in the model quality checks and the number of runs with no convergence in the retrospective pattern.

Table 7.4. SPiCT model estimates and confidence limits for runs 1, 4 and 5.

	Std CPUE + Survey Index					
	1		4		5	
	estimate	c.i.	estimate	c.i.	estimate	c.i.
K	9094	3249 - 25458	20345	8649 - 47858	21644	8958 - 52292
r	0.20	0.14 - 0.29	0.18	0.11 - 0.31	0.21	0.14 - 0.32
q1	0.00070	0.00011 - 0.00432	0.00081	0.00022 - 0.00305	0.00013	0.00005 - 0.00036
q2	0.00104	0.00017 - 0.00633	0.00120	0.00032 - 0.00448	0.00019	0.00007 - 0.00053
B_{2019}	4060	641 - 25709	3559	896 - 14134	21249	7533 - 59943
B_{2019}/B_{MSY}	1.04	0.23 - 4.80	0.40	0.11 - 1.41	2.22	1.36 - 3.63
B_{MSY}	3893	1250 - 12123	8940	3576 - 22350	9560	3519 - 25974
F_{2019}	0.07	0.01 - 0.45	0.08	0.02 - 0.32	0.01	0.00 - 0.04
F_{2019}/F_{MSY}	0.69	0.12 - 3.95	1.05	0.39 - 2.81	0.12	0.05 - 0.28
F_{MSY}	0.10	0.04 - 0.24	0.08	0.03 - 0.18	0.11	0.05 - 0.24
MSY	395	209 - 747	687	337 - 1400	1040	572 - 1892

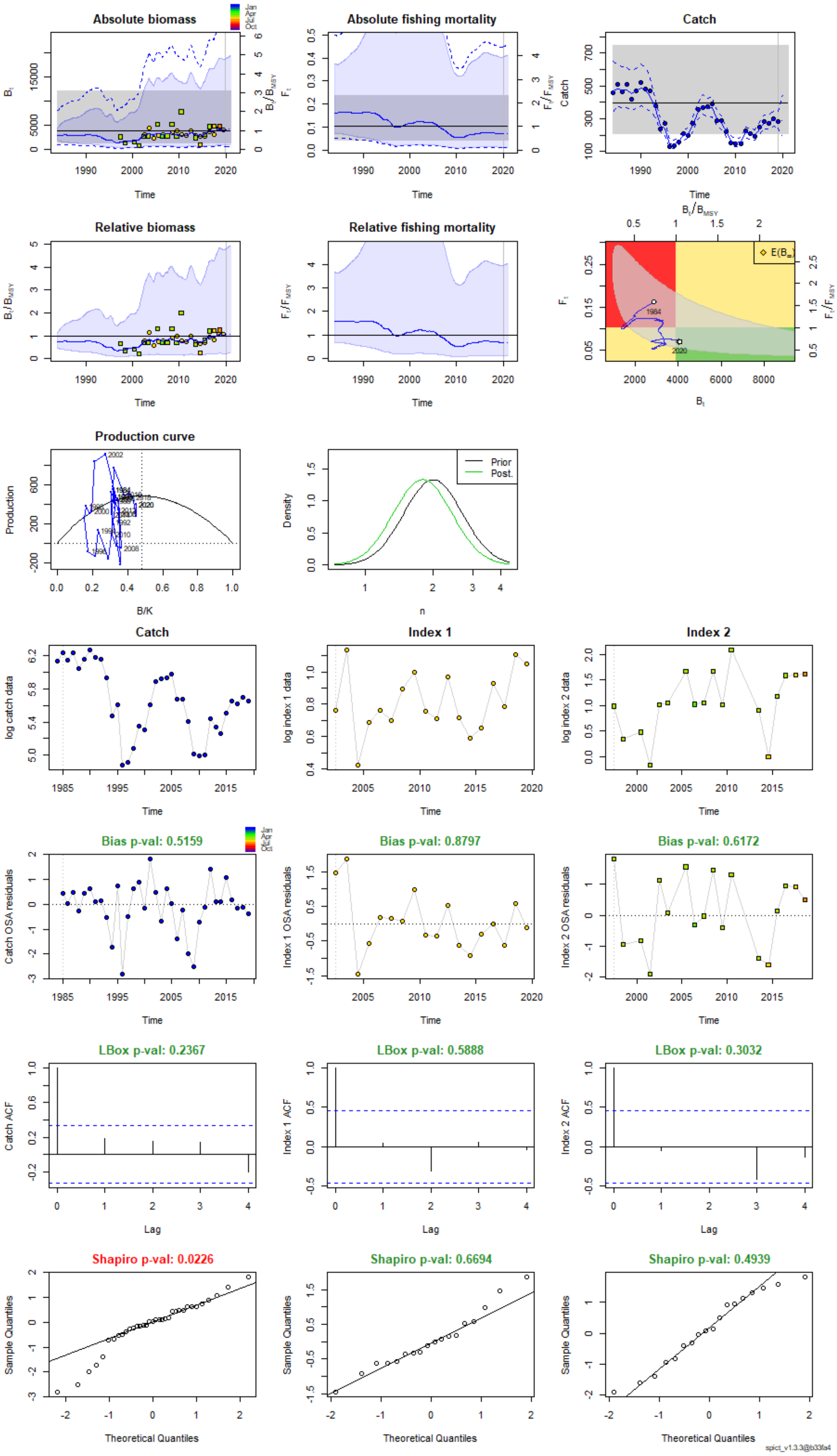

Figure 7.7. Run 1: Model and diagnostic plots.

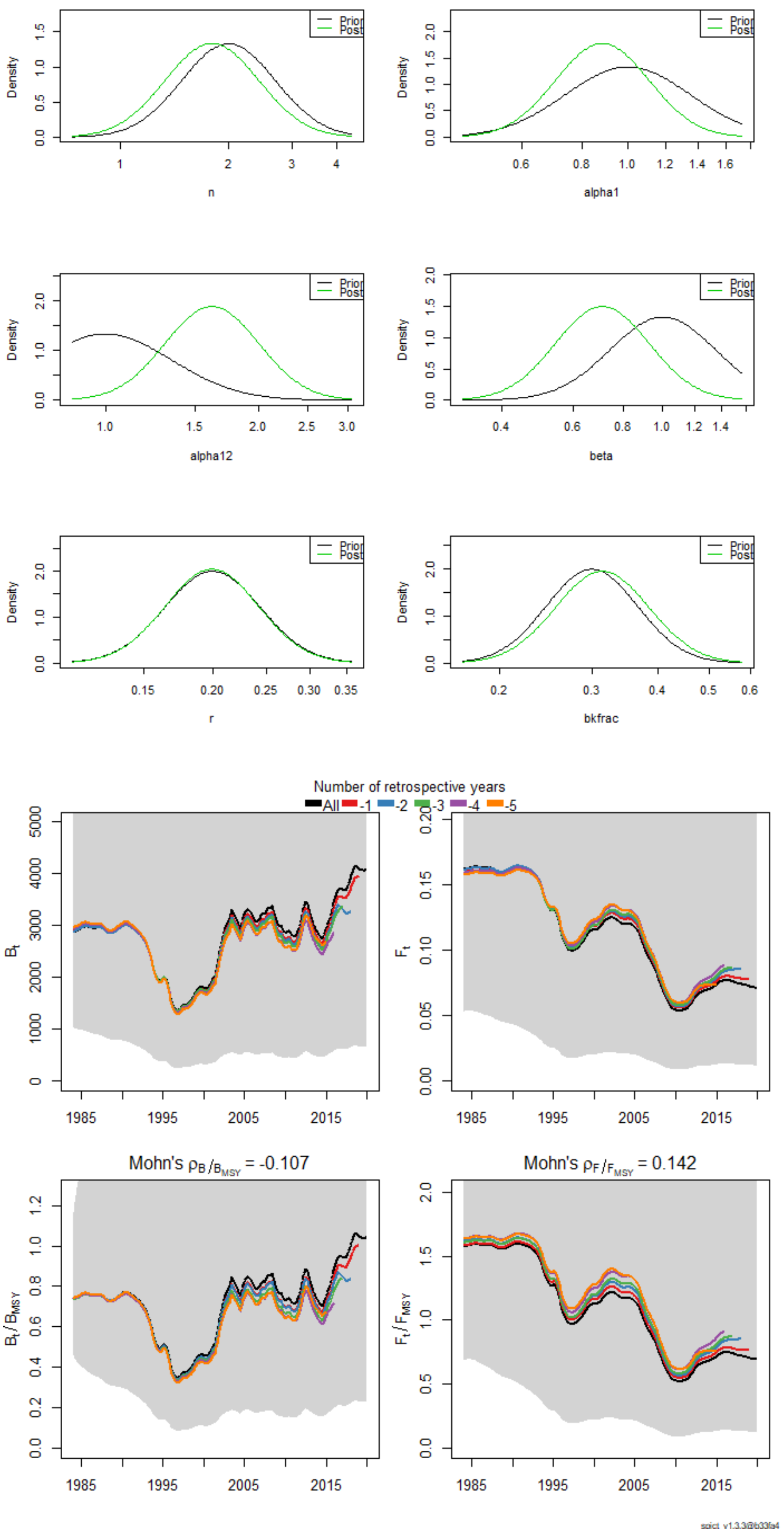

Figure 7.8. Run 1: Priors and posterior distributions of model parameters (upper panel) and retrospective plots (lower panel).

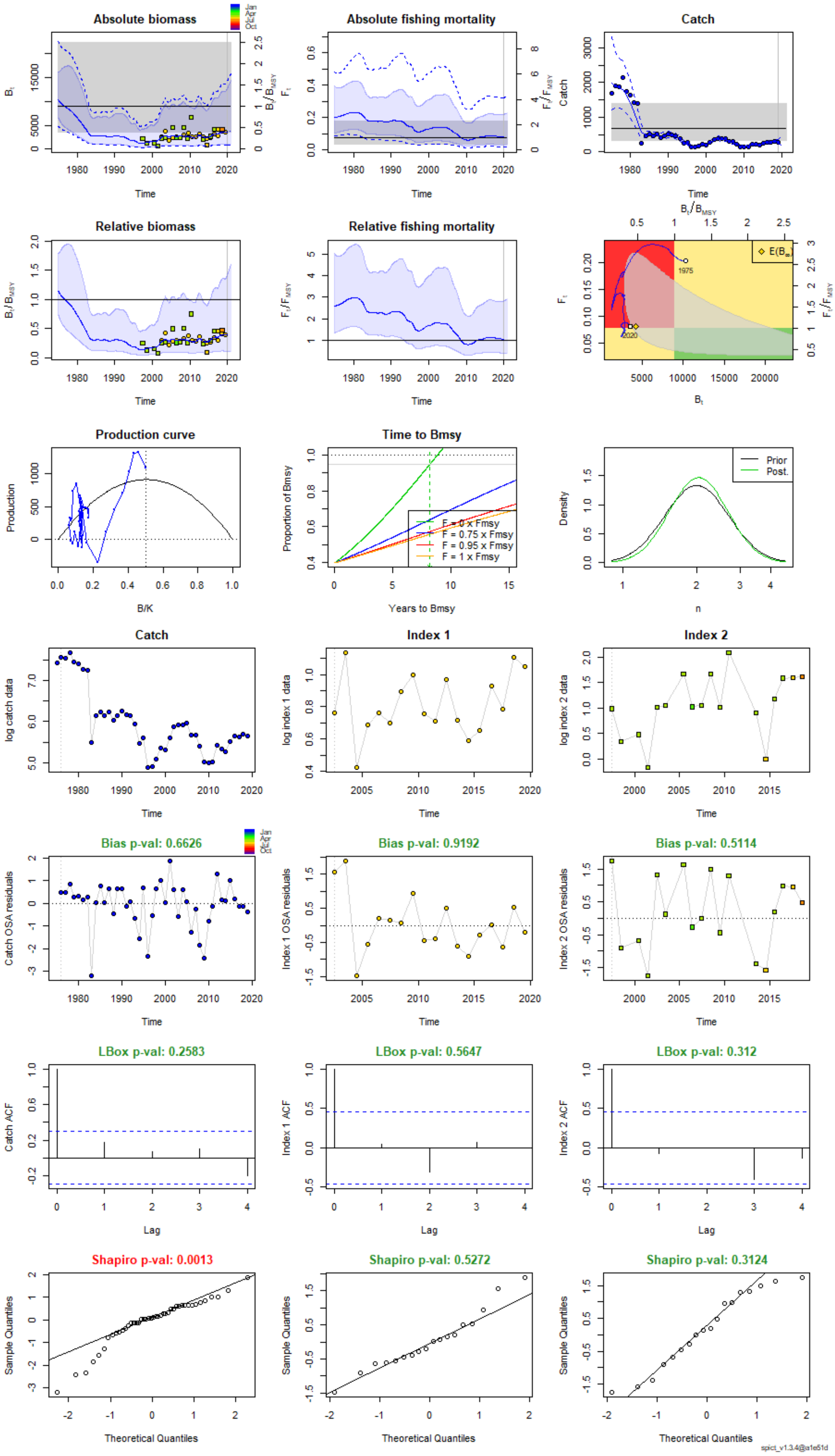

Figure 7.9. Run 4: Model and diagnostic plots.

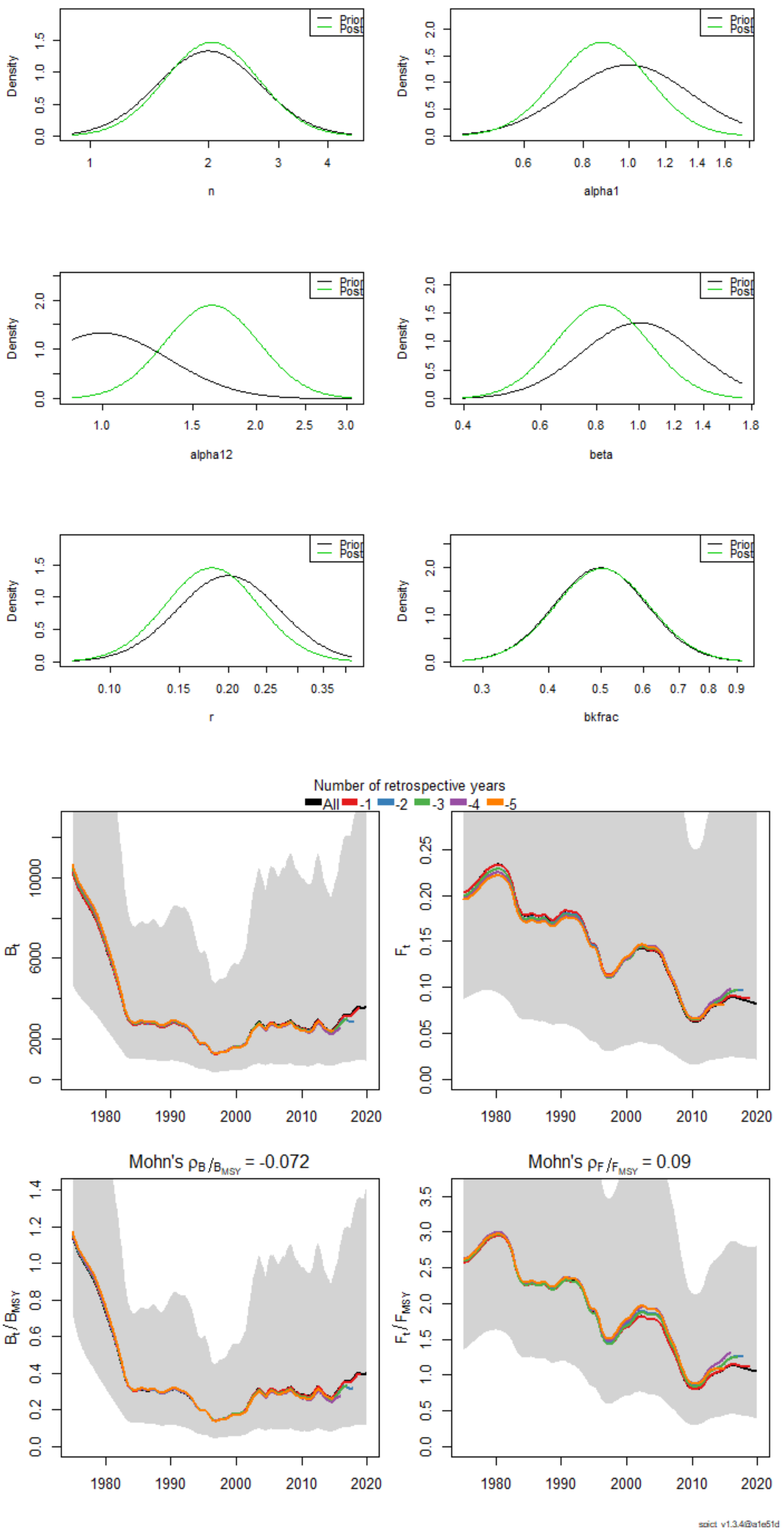

Figure 7.10. Run 4: Priors and posterior distributions of model parameters (upper panel) and retrospective plots (lower panel).

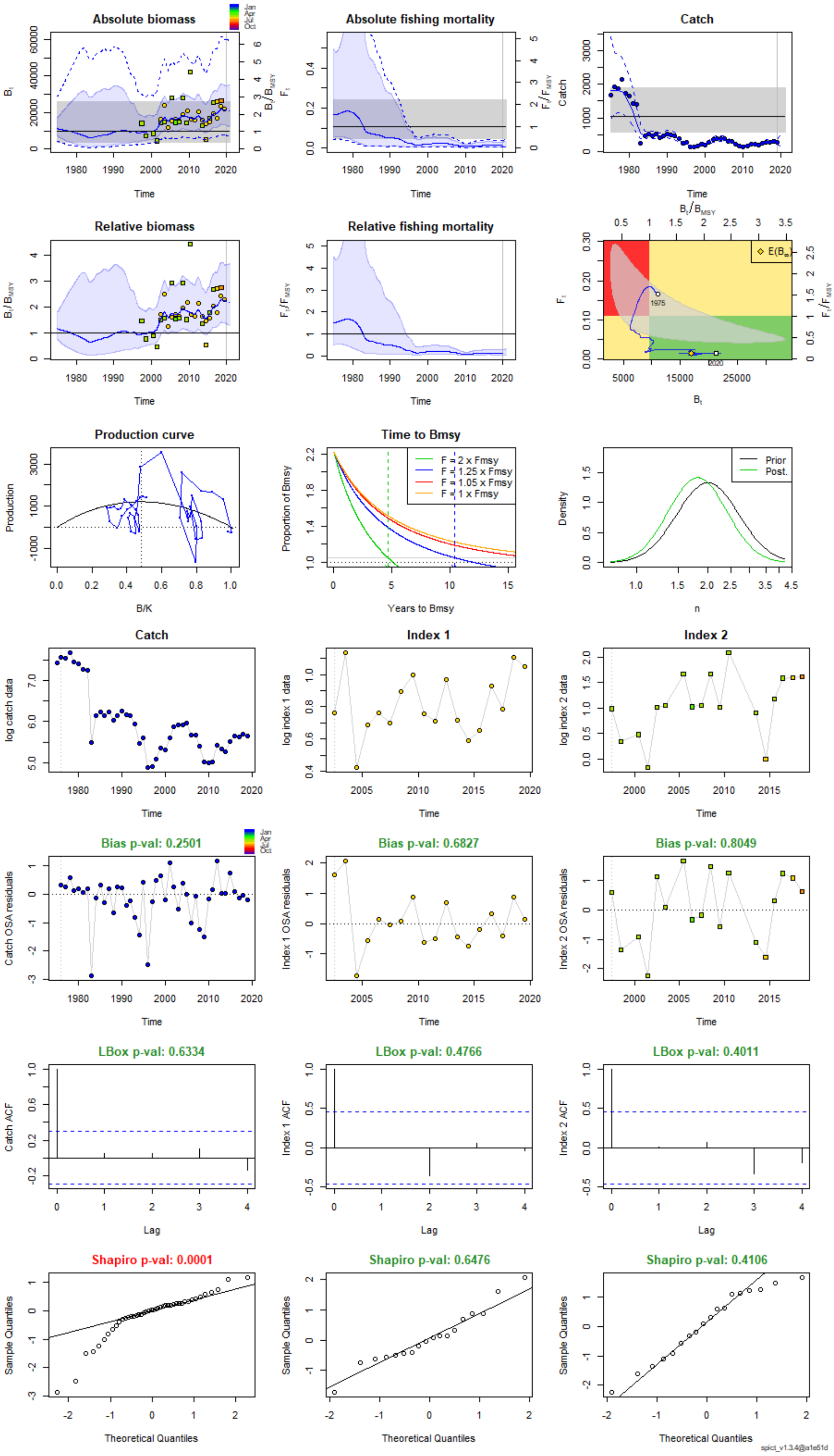

Figure 7.11. Run 5: Model and diagnostic plots.

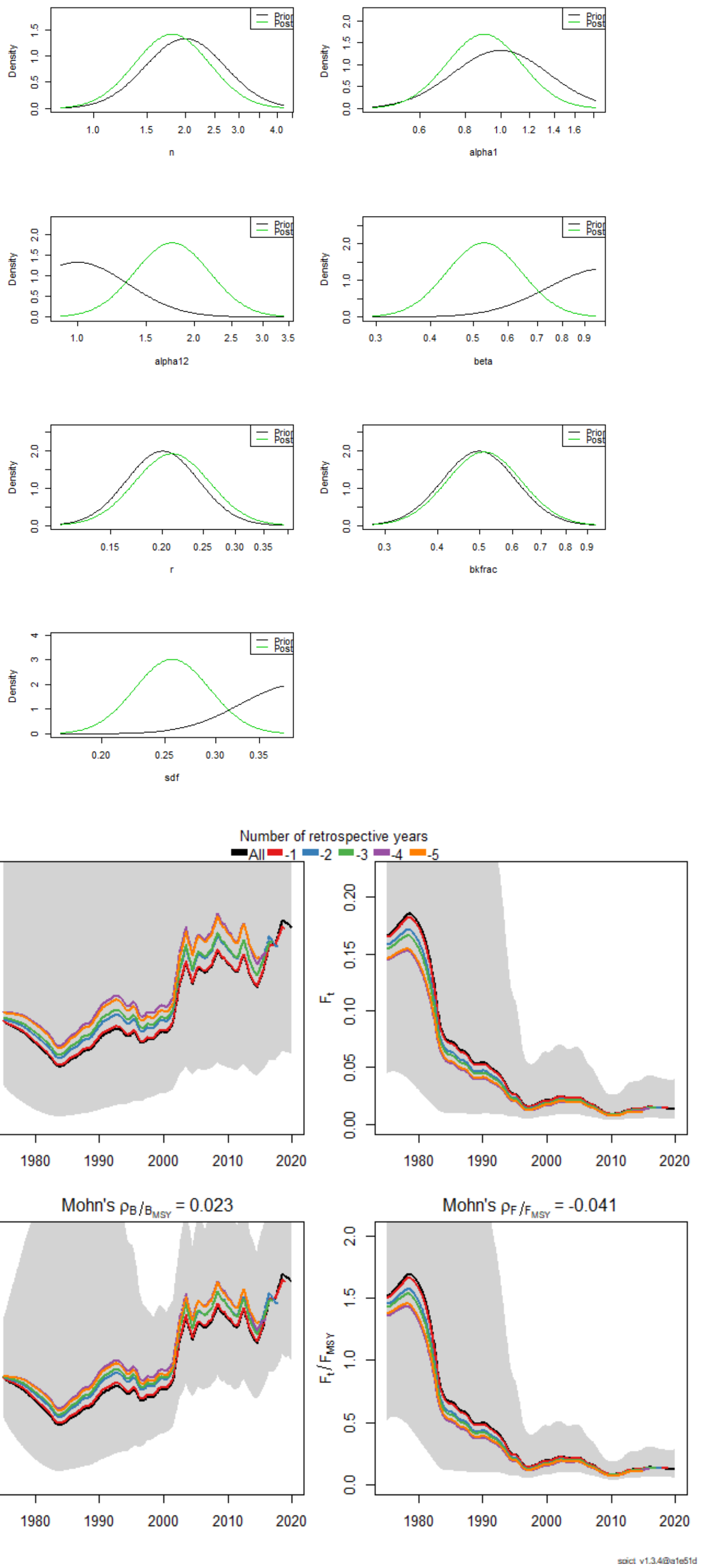

Figure 7.12. Run 5: Priors and posterior distributions of model parameters (upper panel) and retrospective plots (lower panel).

7.3.2 Final assessment

No model configuration was accepted by the Workshop to use as final model assessment.

7.4 Future considerations/recommendations

Due to the wide confidence limits and the contradictory results obtained in the most relevant runs, the state of the stock in relation to reference points is unknown and SPiCT was not accepted to provide assessment and advice for the *Nephrops* FU 28–29 stock. A longer biomass index could allow to understand what was the biomass level when the fishing pressure was high and therefore could provide extra information and help the model to stabilize and produce more coherent results. Also, historical environmental and spatio-temporal data, if available, would also allow understanding if a contraction of the distributional area of the stock occurred, due to the historical high levels of fishing (similarly to what is described for FU 25 and 31), or if a regime shift in productivity had occurred and the stock is now under different conditions.

7.5 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

The assessment model includes catch data from 1984 but catches are available since 1975. The model includes a standardized CPUE from commercial fisheries and a survey covering both FU but with several missing years.

The models that are initiated in 1984 estimate a stock at B_{MSY} in the start of the time-series. However, catches in the 1970s, which peaked in 1979, were generally much larger than catches in the 1980s and afterward. This most likely implies that the fishery has started long before 1984. Therefore, an alternative model configuration should be tested that includes available historical catches as agreed at the data meeting.

To further explore the robustness of the current reference model for advice, the analyst presented additional residual diagnostics and retrospective analyses during the benchmark workshop for two additional runs using a lower initial depletion prior, e.g. logbkratio = c(log(0.5),0.5,1) and c(log(0.3),0.5,1).

A perhaps more important aspect concerns the standardization of the commercial CPUE. Although the CPUE standardization procedure was done thoroughly, the model used to standardize the commercial CPUE does not contain the interaction between space and time. This is particularly relevant for a stationary species as Norway lobster where CPUE can exhibit hyperstability in the commercial fisheries through targeting, sequential depletion by moving to relatively unfished areas or due hyperstability in abundance in the core area. Thus, any model that aims to standardize commercial CPUE of Norway lobster should ideally include a spatio-temporal effect. Also, it would be ideal to have a smaller spatial resolution than the fishing grounds in the standardization since those data are available. This could for instance be accomplished by using a GAM with the interaction between latitude, longitude and time. Spatio-temporal differences in abundance linked to environmental changes and/or depletion implies that the use of spatio-temporal models for standardizing fisheries-dependent CPUE data will be increasingly necessary in the future (Gruss *et al*., 2019).

An alternative model configuration was tested, which only considers the survey as unbiased index and excludes the commercial CPUE, but the results were still inconclusive given the data available. A series of alternative runs were requested at the meeting for which the analyst should use the historical catches, the survey and the commercial CPUE excluding the first 4 years of the time-series. The reason of the exclusion is that the first 4 years shows a very rapid increase, which is not corroborated by the survey during the same period. Moreover, the models should be run with a lower and tighter prior on the b/k ratio, e.g. logbkratio = c(log(0.5),0.3,1) and c(log(0.3),0.3,1).

Additional runs show similarly increasing trends in recent years but these resulted in very different states of the stock, which is dependent on the prior and variance assumptions for some of the key parameters.

Conclusions

Given the available input data, it is not possible to distinguish between two alternative stock states. It is therefore suggested that the stock remains in category 3, with the trend informed by the survey or by a fully standardized commercial CPUE if surveys are not available.

7.6 References

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8 Norway lobster (*Nephrops norvegicuss*) in Division 8.c, Functional Units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (nep.fu.2627)

8.1 Introduction

Stock Definition

The Norway lobster (*Nephrops norvegicus*) is distributed along the continental slope off the west Galicia and north of Portugal at depths ranging from 80–500 m (Fariñas, 1996). Its distribution is limited to muddy sediments with 10–100% silt and clay content, required to excavate burrows (Bell *et al*., 2013).

The *Nephrops* stock in FU 26 and FU 27 are included within the ICES Division 9a. FU 26 extends along the Atlantic area off the northwestern Spanish coast, south of Cape Finisterre (statistical rectangles 14E0, 13E0, 13E1), whereas FU 27 covers the Atlantic area off northern Portugal (statistical rectangles 6E0–12E0) (Figure 8.1.1). Although FUs 26 and 27 are different stocks, landings records are not differentiated prior 1996 and they are assessed together.

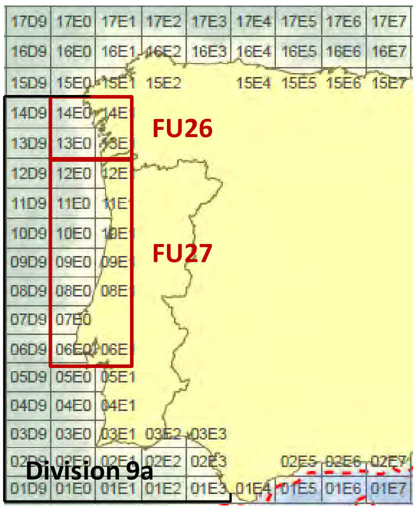


Figure 8.1.1. ICES Division 9a. Red square indicates FU26 (Western Galicia) and FU27 (Northern Portugal).

Fishery information

Nephrops is caught in a mixed bottom-trawl fishery by the métier targeting different species such as hake, anglerfish and megrim. *Nephrops* represents a minor percentage in the composition of total trawl landings and can be considered as by-catch although it is a very valuable species. The *Nephrops* fishery takes place throughout the year, with the highest landings usually being made in the spring and summer.

Landings are reported mainly by Spain and minor quantities by Portugal. The catches are taken by the Spanish bottom trawl fleet fishing on the Western Galicia (FU 26) and Northern Portugal (FU 27) fishing grounds and in minor quantity by the Portuguese artisanal fleet fishing with traps in FU 27 (ICES, 2020).

Discards are considered negligible. Few animals are caught under the minimum size being the discard related to quality (i.e. broken or soft shells).

Since 1990 onwards there has been a marked downward trend in landings. Available time-series starts in 1975 with records of 622 t, being below 50 t for the 2005–2011 periods and below 10 t in 2012. Landings were minimal since that date (mean value 4 t) (ICES, 2020). In general, fishing effort and commercial LPUE also show a decreasing trend during the time-series (ICES, 2020). Fishing effort remained stable at very low level since 2010 and LPUE index was very low since 2012 and lower than 1 Kg/trip since 2014, indicating that the abundance of these FUs is very poor.

Independent fishery information

The International Bottom Trawl Surveys (IBTS) conducted in the north of Spanish **(SP-NSGFS-Q4 IBTS)** and in Portuguese waters **(PtGFS-WIBTS-Q4)** can be used to derivate an independent fishery index in FU 26 and FU27, respectively, using hauls included in statistics rectangles in each FU. SP-NSGFS-Q4 IBTS index in FU26, show a decreasing trend since the beginning of 1990s with very low values since 2002. In FU27, PtGFS-WIBTS-Q4 index fluctuated since late 1980 to 2000 remaining a very low level since this date although a peak was observed in 2015.

A new survey in FU26 (**GALNEP26)** was promoted by Marin Fishing Industry (OPROMAR, Productores de Pesca Fresca del Puerto y la Ría de Marín) in 2019. This survey is carried out yearly in August, onboard a commercial vessel in order to estimate *Nephrop*s abundance index in FU 26 (Vila *et al*., 2020). An observer was onboard during the survey and it was supervised by the IEO. GALNEP26 survey index spatial analysis show a reduction of the *Nephrops* distribution area in relation to the historical one.

Management Regulation

Nephrops is managed in the area by an annual TAC (applying to the whole of ICES Division 9a, of which no more than 6% may be taken in FUs 26 and 27) and technical measures. European Union regulations establish 20 mm carapace length (CL) as a minimum landing size. Few animals are caught under size, so discards are considered negligible and are mainly related to quality (broken or soft shells).

A Recovery Plan for the southern hake and Iberian *Nephrops* stocks was in force since the end of January 2006 (Council Regulation (EC) No. 2166/2005). The aim of the recovery plan was to rebuild the stocks within ten years, with a reduction of 10% in F relative to the previous year and the TAC set accordingly. Although no clear targets were defined for Norway lobster stocks in the plan, the same 10% reduction was applied to these stocks' effort and TAC. The number of allowed fishing days is set in each year regulations. ICES had not evaluated the recovery plan for *Nephrops* in relation to the precautionary approach. This plan was based on precautionary reference points for southern hake that are no longer appropriate.

In order to reduce F on *Nephrops* stocks in this Division even further, a seasonal ban was introduced in the trawl and creel fishery for two boxes, located in FU 26 and 28, in the peak of the *Nephrops* fishing season. These boxes are closed for *Nephrops* fishing in June–August and in May–August, respectively (Council Regulation (EC) No 850/98).

A Fishing Plan for the Northwest Cantabrian ground was established in 2013 (AAA/1307/2013, BOE, 2013) and modified in 2014 (AAA/417/2014, BOE, 2014). These regulations establish a quota assignment system for several stocks (including *Nephrops*) by vessel.

A new Management Plan for Western Waters was established in 2019 for demersal species including *Nephrops* in these FUs (Regulation (EU) 2019/472, of 19 March 2019). In the current Management Plan for Western Waters, applied to 2020 onwards, no effort limitations were established.

Unwanted catches from *Nephrops* are legislated by the discard plan for demersal fisheries in southwestern waters for the period 2019–2021 (Council Regulation (EC) No 2018/2033), under which they are exempted from the landing obligation based on the species' high survival rates. This exemption applies to all catches of Norway lobster from ICES subareas 8 and 9 with bottom trawls, and the discards shall be released whole, immediately and in the area where they were caught.

Historical Stock Assessment

Nephrops in FU26–27 had been assessed since 1990 (ICES, 1990). The last analytical assessment for these FUs was carried out by the WGHMM in 2006 (ICES, 2006). XSA was used with "catch-at-age" data generated by slicing length distributions employing the L2AGE program. An assessment with combined sexes was carried out, although the slicing was applied for each sex separately and the resulting catch-at-age matrices by sex added up for the assessment. Prior to 2005, an assessment by sex was conducted but the WG proposed to carry out an assessment for both sexes combined, considering the advantages for management.

The 2006 assessment was calibrated using data from a single commercial LPUE series, where the definition of fishing effort was based on nominal effort. The results were accepted only as indicative of stock trends and not used for forecast.

After 2006, no improvements in relation to a methodological assessment were achieved and the WG did not attempt any further analytical assessment for FU 26–27. The time-series of fisheries data are updated every year and LPUE series used to depict the stock trends.

Since 2012, the advice for this stock was based on fishery SP-MART LPUE and effort trend, according to the ICES data-limited approach (ICES, 2012). This stock is classified according to Data-Limited Stocks (DSL) category 3.1.4.: stocks with extremely low biomass.

8.2 Input data for stock assessment (ToR 1 & 2)

Available data for *Nephrops* in FU26–27 were presented during the Data Evaluation Workshop celebrated in November 2020 to evaluate the appropriateness of them in order to use as input data in the SPiCT model. This information is summarized below:

Landings and discards

Spanish landings are based on sales notes which are compiled and standardized by IEO. Since 2013, trips from sales notes are also combined with their respective logbooks, which allow georeferencing the catches. Spanish and Portuguese landings are uploaded to the InterCatch database. Annual landings data by FU and country for the period 1975–2019 are shown in Table 8.2.1. Additionally, quarterly landings information in FU26 and FU27 only by the Spanish fleet is also available.

Discards are considered negligible, based on the results obtained from the DCF discard sampling programme onboard the Spanish bottom trawl fleet (OTB_DEF_>=55_0_0), since 2004. When occurring, discards of *Nephrops* are related to quality (i.e. broken or soft shells).

Table 8.2.1. *Nephrops* landings by FU and country.

	Spain		Portugal	Total
Year	FU 26**	FU 27	FU 27	FU 26-27
1975	622			622
1976	603			603
1977	620			620
1978	575			575
1979	580			580
1980	599			599
1981	823			823
1982	736			736
1983	786			786
1984	604		14	618
1985	750		15	765
1986	657		37	694
1987	671		71	742
1988	631		96	727
1989	620		88	708
1990	401		48	449
1991	549		54	603
1992	584		52	636
1993	472		50	522
1994	426		22	448
1995	501		10	511
1996	264	50	17	331
1997	359	68	6	433
1998	295	42	8	345
1999	194	48	6	248
2000	102	21	9	132
2001	105	21	6	132
2002	59	24	4	87
2003	39	26	8	73
2004	38	24	9	71
2005	16	16	11	43
2006	15	17	12	44
2007	20	17	10	47
2008	17	12	13	42
2009	16	5	10	31
2010	3	14	4	21
2011	8	8	4	20
2012	3	4	1	8
2013	1	<1	1	3
2014	1	<1	1	4
2015	<1	<1	<1	2
2016	3	<1	2	5
2017	<1	0	2	3
2018	<1	1	0	2
2019	1	1	4	6

**Prior 1996, landings of Spain recorded in FU 26 include catches in FU 27

Effort and LPUE

Effort and LPUE of Spanish Marin port (SP-MATR) data are available for 1994–2019 period. Since 2013, the Spanish concurrent sampling is used to raise the FU26–27 observed landings to total effort by métier. Table 8.2.2 shows the available fishing effort and LPUE time-series.

Table 8.2.2. Fishing effort and LPUE for SP-MATR fleet.

Year	Landings (t)	SP-MATR trips	LPUE (kg/trip)
1994	234	2692	86.9
1995	267	2859	93.4
1996	158	3191	49.5
1997	245	3702	66.2
1998	188	2857	65.8
1999	134	2714	49.4
2000	72	2479	29
2001	80	2374	33.7
2002	52	1671	31.1
2003	59	1597	36.9
2004	31	1980	15.7
2005	17	1629	10.4
2006	18	1547	11.6
2007	22	1196	18.4
2008	17	980	17.3
2009	15	854	17.6
2010	8	539	15.3
2011	4	543	6.5
2012	1	492	2.1
2013	<1	419	1.0
2014	<1	494	0.8
2015	<1	384	0.7
2016	<1	403	0.6
2017	<1	390	0.3
2018	<1	398	0.9
2019	<1	383	0.3

Length frequency

Length composition of *Nephrops* in FU26–27 by sex is available for the period 1988–2019 (ICES, 2020).

Surveys

Three different survey indices are available for *Nephrops* in FU26–27.

The **GALNEP26** is a survey carried out onboard a commercial vessel in August in order to estimate *Nephrops* abundance index in FU 26 following a systematic sampling design (Vila *et al.*, 2020). An observer is onboard during the survey and it is supervised by the IEO. This survey starts in 2019 and only two years are available, so the time-series is very short to use as input in the SPiCT model.

The **SP-NSGFS-Q4 IBTS** covers the northern Spanish shelf comprised in ICES Division 8c and the northern part of 9a, including the Cantabrian Sea and off Galicia waters. This survey usually starts at the end of the 3rd quarter (September) and finishes in the 4th quarter. Survey data are available from 1984 to 2019 but no survey was carried out in 1987. It is a bottom trawl survey with a random stratified by depth strata sampling design from 70 to 800 m. Depth strata are 70–120 m, 121–200 m, 201–500 m, 501–800 m. Prior 1997, the lowest stratum covered since 30 m depth. However, hauls at depth lower than 70 m were not used, as *Nephrops* is not distributed this deep. Total area is divided into five sectors (Miño-Finisterre, Finisterre-Estaca, Estaca-Peñas, Peñas-Ajo and Ajo-Bidasoa). Miño-Finisterre sector corresponds to statistics rectangles (14E0, 13E0, 13E1) which compound *Nephrops* FU 26 stock (Western Galicia) (Figure 8.2.1). The area of this sector is 4327 Km^2. This survey is focused to estimate the abundance of demersal species and it is not designed to estimate *Nephrops* abundance. Survey index is expressed as the mean catch per haul using hauls included in ICES statistical rectangles in FU26.

Portuguese survey **(PtGFS-WIBTS-Q4)** is carried out in Portuguese continental waters in the 4th quarter of the years. The main objective of the survey is to estimate the abundance of the most important commercial species in the Portuguese trawl fishery but it is not specifically designed to estimate the *Nephrops* abundance. *Nephrops* data are available from 1985 to 2017. No survey could be conducted in the last two years due to vessel issues. Survey extends from latitude 41°20' N to 36°30' N (ICES Division 9a) and from 20–750 m depth following 20–100 m, 101–200 m, 201–

500 m and 501–750 m strata design. This survey is divided in eleven sectors (Figure 8.2.1), six of them correspond to FU 27 (Caminha,CAM; Matosinhos,MAT; Aveiro,AVE; Figueira,FIG; Berluga,BER; and Lisbon,LIS) covering a total area of 19 055 Km². So, hauls conducted in those sectors can be used to derive a stratified index in this FU. *Nephrops* survey index is expressed as the mean catch per haul using hauls included in ICES statistical rectangles in FU27 (6E0–12E0).

Recommendations on the most appropriate series to be used for SPiCT and potential improvements of them

Experts recommended using catch and independent fishery data as input in the SPiCT model for *Nephrops* in FU26–27 assessment. Nevertheless, the IBTS survey index expressed as the *Nephrops* mean weight from hauls carried out within statistics rectangles located in each FU was not considered appropriated, because depth was not taken into account. Experts recommended carrying out a spatial-temporal analysis from the survey's information in FU26 (SP-NSGFS-IBTS-Q4) and FU27 (PtGFS-WIBTS-Q4) and to obtain a combined biomass index for FU26–27 stock.

Three tasks were carried out in order to get the experts' recommendations:

1. Average Stratified survey Index estimate for FU 26–27 from the Spanish and Portuguese IBTS survey carried out in FU 26 and FU 27, respectively.
2. Spatial analysis from the Spanish and Portuguese IBTS survey carried out in FU 26 and FU 27, respectively.
3. Spatial-temporal model for the Spanish and Portuguese IBTS survey index carried out in FU 26 and FU 27, respectively: New combined index estimation.

TASK 1: Average Stratified survey Index estimate for FU 26-27 from the Spanish and Portuguese IBTS survey carried out in FU 26 and FU 27, respectively

A new depth stratified biomass index for the total area covering FU26–27 (23 382 Km²) was estimated considering the following sectors (Figure 8.2.1): Miño-Finisterre (GAL), Caminha (CAM), Matosinhos (MAT), Aveiro (AVE), Figueira (FIG), Berluga (BER) and Lisbon (LIS), as parts of a unique survey and taking into account the area corresponding to each depth stratum (Table 8.2.3). *Nephrops* weight by haul was standardized to one hour. Figure 8.2.2 shows the new stratified biomass index obtained in FU26 (Western Galicia), FU27 (Northern Portugal) and FU26-27 (whole area covering these stocks).

Table 8.2.3. Area in Km² by sectors and depth strata covered by Spanish and Portuguese IBTS survey in FU26 and FU27.

	Sectors	Depht strata				Total area (Km²)
SP-NSGFS-Q4 IBTS (Km²)		70-120 m	121-200 m	201-500 m	501-750 m	
	GAL	1181	2190	956	na	**4327**
PtGFS-WIBTS-Q4 (Km2)		20-100m	101-200m	201-500m	501-750m	
	CAM	1438	635	228	171	**2472**
	MAT	1384	862	179	171	**2596**
	AVE	1569	1096	266	257	**3189**
	FIG	1379	1608	445	343	**3774**
	BER	917	865	372	257	**2411**
	LIS	1550	1561	1073	429	**4613**
FU26-27 (Km2)						**23382**

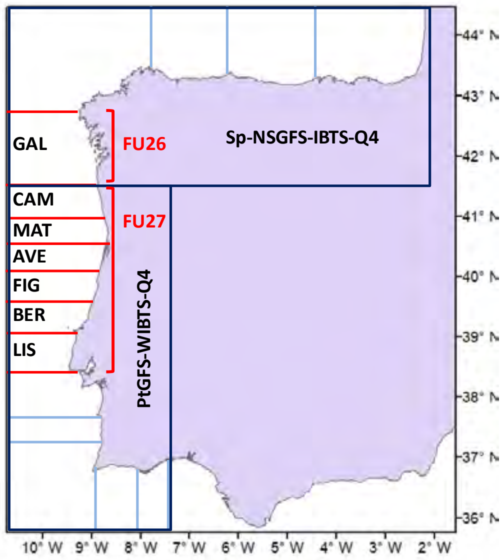


Figure 8.2.1. Area and different sectors covered by Spanish IBTS survey (Sp-NSGFS-IBTS-Q4) and Portuguese IBTS survey (PtGFS-WIBTS-Q4). Sectors in red correspond to FU26 (GAL) and FU27 (CAM, MAT, AVE, FIG, BER, LIS).

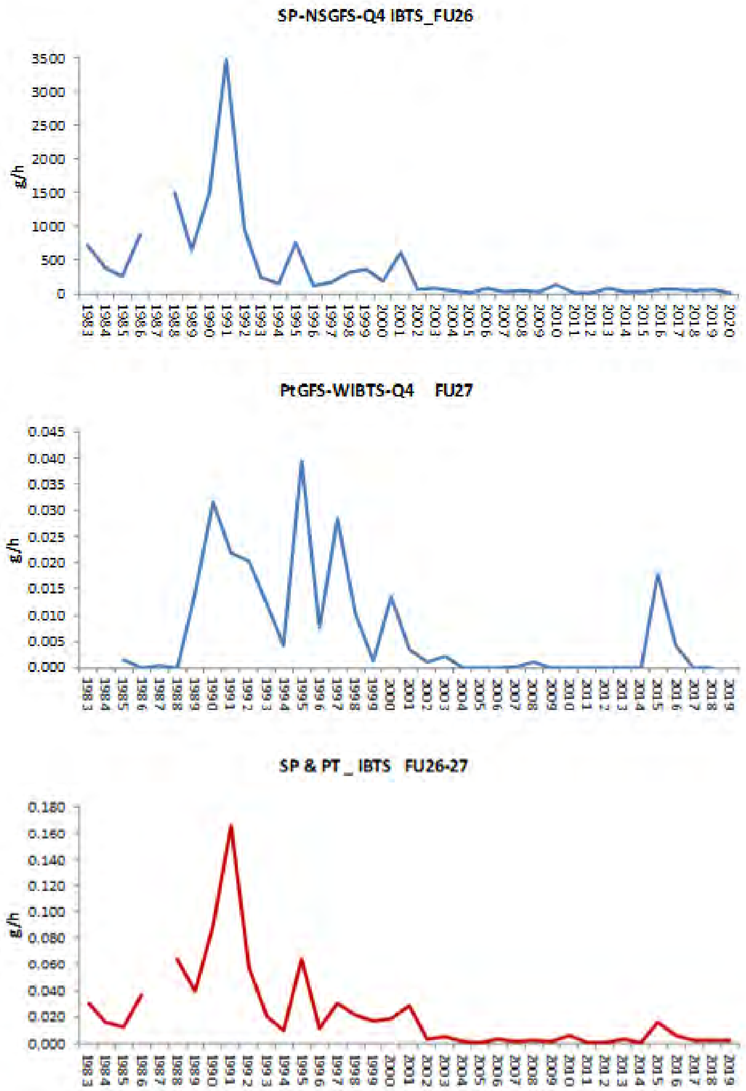


Figure 8.2.2. New stratified by depth biomass index in FU26 (above), FU27 (middle) and FU26–27 (below).

TASK 2: Spatial analysis from the Spanish and Portuguese IBTS survey carried out in FU 26 and FU 27, respectively

The *Nephrops* spatial distribution from Spanish survey in FU26 and Portuguese survey in FU27 for the all time-series (1983–2019) is shown in Figure 8.2.3. *Nephrops* is mainly distributed in Miño-Fisnisterre sector (GAL) in FU26 from about 100 to 700 m depth and Caminha sector (CAM) in the north part of FU27 from 100 to 500 m depth. In the rest of the FU27, *Nephrops* patches occur particularly in Figueira sector (FIG) in the deepest stratum and Berluga sector (BER) in a higher bathymetric range. In Lisbon sector (LIS), *Nephrops* is present in a small patch in front of Cascais about 350 m depth.

A picture of the spatial distribution of *Nephrops* biomass index in FU26-27 for some years of the time-series is shown in Figure 8.2.4 indicating a declining trend of the biomass index since 1983, as well as a reduction of the number of *Nephrops* patches in FU26–27.

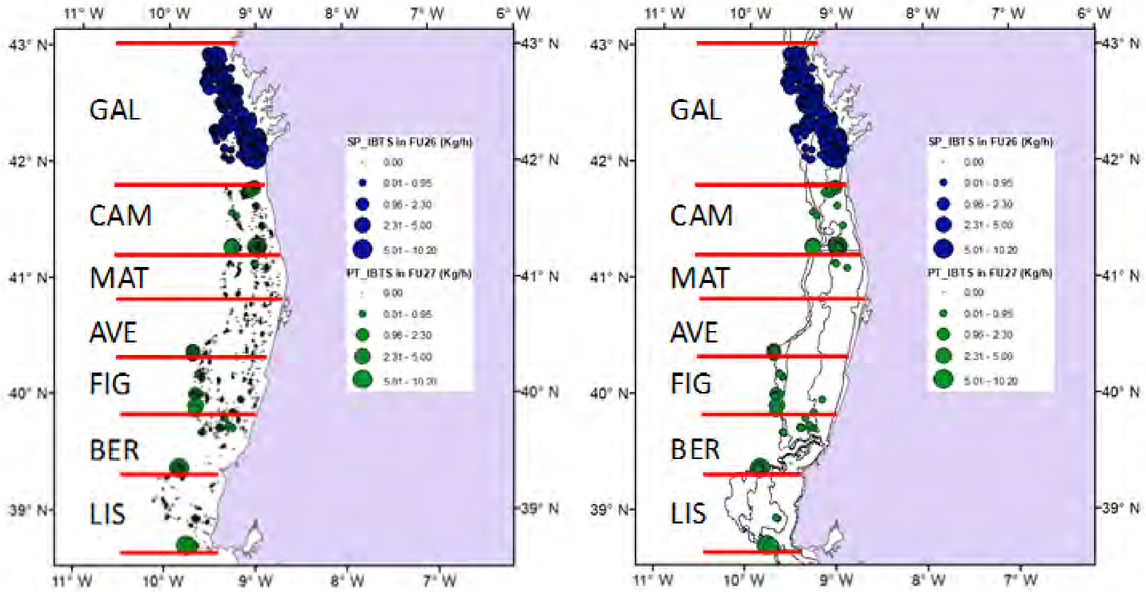


Figure 8.2.3. Spatial distribution of the *Nephrops* biomass index in FU26–27 (1983–2019) from the Spanish and Portuguese IBTS survey in FU26 and in FU27, respectively. Including hauls with zero *Nephrops* caught (left) and including bathymetry (right).

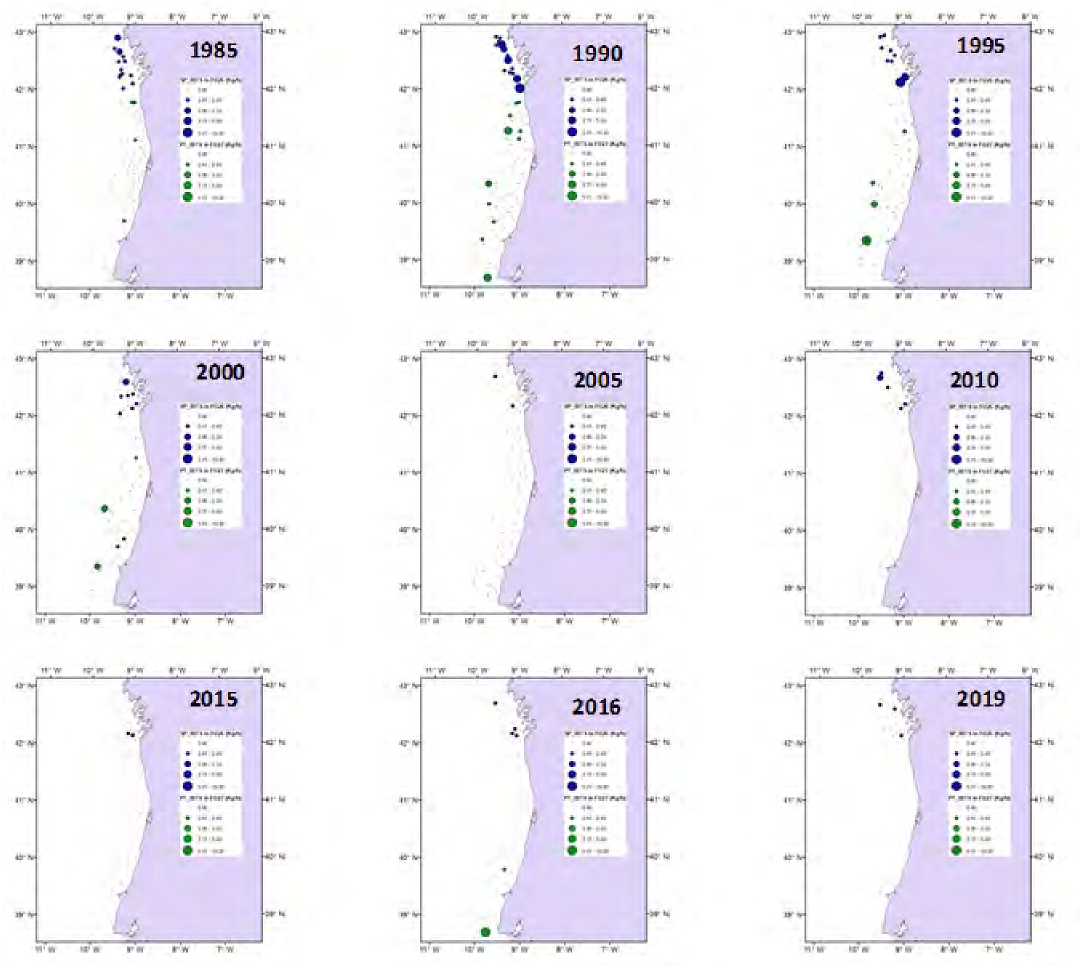


Figure 8.2.4. Spatial distribution of the *Nephrops* biomass index in FU26-27 for some years of the time-series. No Portuguese survey in 2019.

TASK 3: Spatial-temporal model for the Spanish and Portuguese IBTS survey index carried out in FU 26 and FU 27, respectively: New combined index estimation

In order to obtain a combined index for *Nephrops* in FU26–27 stock, a Bayesian hierarchical model was used. In particular the biomass index from Spanish survey in Fu26 and Portuguese survey in FU27 were used as response variables, while the bathymetry of the fishing haul, the time of the fishing haul and the geographical position (latitude and longitude) were included as explicative variables. Bathymetry was modelled as second random walk effect and the time and the geographical position as continuous variables. In addition, an autoregressive temporal component (AR1) was used to model the year of the survey. Finally, a survey random effect was added to account for the different survey catchability (e.g. gear, vessel, etc).

Response variables were log-transformed before being used in the model to reduce variability and to meet the theoretical assumptions of the model (e.g. normality and homoscedastic variance).

Models were fitted using the integrated nested Laplace approximation approach INLA (Rue *et al*., 2009) in the R software (R Core Team, 2019). Default INLA priors were used for the all the parameters.

Models were selected by testing all possible variables combination using the Watanabe Akaike information criterion (WAIC) (Watanabe, 2010) for goodness of fit and the log-conditional predictive ordinates (LCPO) (Gneiting and Raftery, 2007) for predictive quality measures, based on a leave-one-out cross-validation. WAIC and LCPO scores are inversely related to the compromise between fit, parsimony and predictive quality, i.e. lower scores denote better models.

For a first exploratory analysis it was possible to see that the Spanish survey caught much more *Nephrops* that the Portuguese one (Figure 8.2.5.) as previously has been noted in Task 2.

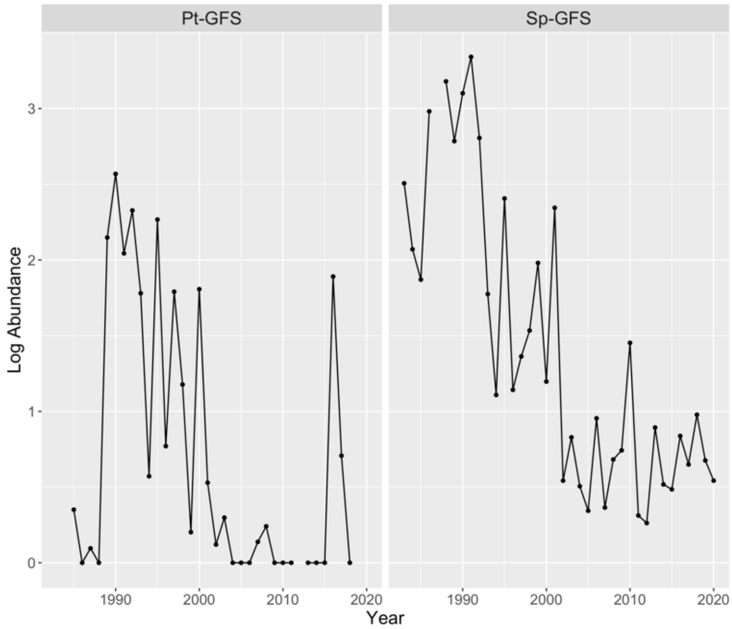


Figure 8.2.5. Log-transformed biomass index in kg/h for the historical series for the Portuguese (Pt-GFS) and Spanish (Sp-GFS) index.

The final model selected for the lowest WAIC and LCPO values, was the one that included the bathymetry as explicative variables, jointly with the survey random effect and the AR1 effect of the year. The others variables were removed subsequentially from the model as the WAIC and LCPO values were higher. Overall, the model converged without any issue. The bathymetry showed a dome-shaped mean functional response as showed in Figure 8.2.6. The combined index for this *Nephrops* stock in FU26–27 is represented in Figure 8.2.7.

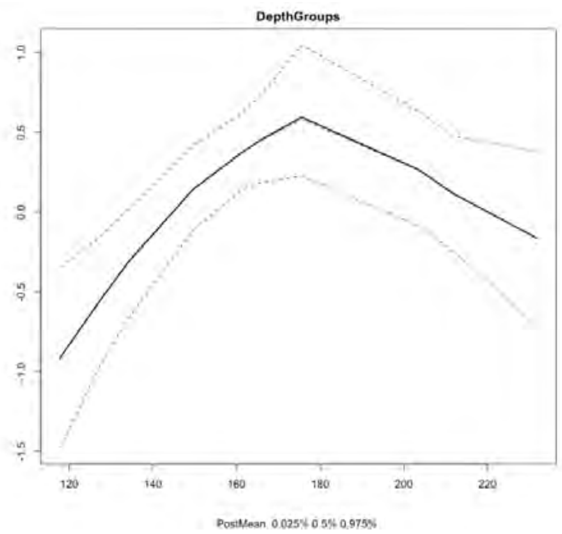


Figure 8.2.6. Second random walk effect for the bathymetry variable.

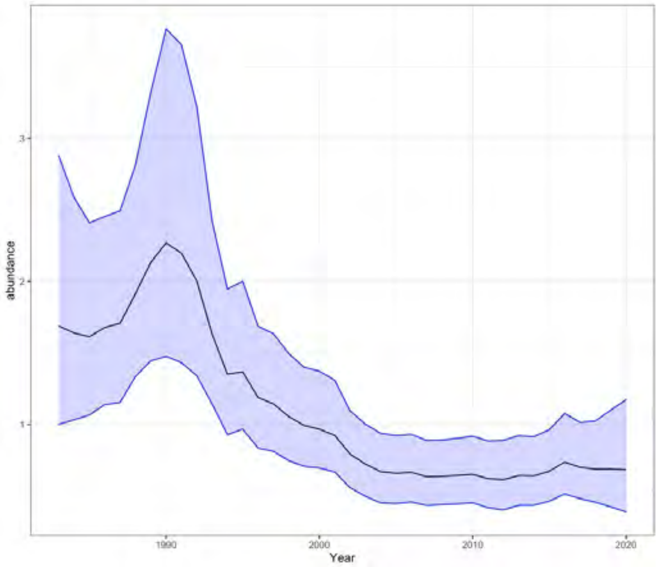


Figure 8.2.7. Combined index for *Nephrops* in FU26–27 derived from the Bayesian model.

8.3 Stock assessment (ToR 3)

The stock assessment was performed using the software SPiCT v1.3.3 (Pedersen and Berg, 2017) available at https://github.com/DTUAqua/spict.

8.3.1 Exploratory assessments

SPiCT exploratory runs using defaults priors were conducted during the Data Evaluation Workshop in November 2020 (WKMSYSPiCT, WD: Vila, 2020). Those showed that when CPUE and effort are separately used as inputs in the model, some violations of the model assumptions based on-step-ahead residuals and normality were observed. Additionally, non-convergence of the retrospective analysis was found and stochastic reference points could not be derived. The model converged when IBTS survey index in FU26 (SP-NSGFS-IBTS-Q4-FU26) and in FU27 (PtGFS-WIBTS-Q4-FU27) were used as inputs, but results were not appropriated. The main issues were the huge uncertainty, problems with the production curve and the strong tendency in the retrospective pattern. Experts recommended using stronger priors related to the production curve n and initial depletion level b/k.

Input data

For the Benchmark Workshop in February 2021, landings from 1975 to 2019 and a fishery-independent biomass index from 1983–2019 (there was no survey in 1987) were used as input data in the SPiCT model. Three different scenarios were considered depending on the biomass index used:

- **Scenario 1:** Landings FU26–27 + New combined biomass index for FU26–27;
- **Scenario 2:** Landings FU26–27 + Stratified biomass index for FU26–27;
- **Scenario 3:** Landings FU26–27 + Stratified biomass index for FU26.

Scenario 3 was tested because *Nephrops* is distributed mainly in FU26 as it has been showed previously.

For all scenarios:

a) the biomass index time-series was scaled to mean 1 in order to obtain a better numerical stability

mstd <-function(x) x/mean(x,na.rm=TRUE)
data$DEM = mstd(data$DEM)

b) An extra uncertainty was applied to landings from 1975 to 1980 as during this period is possible that a wrong gear identification of some trips could occur and as consequence *Nephrops* landing were lower.

inp$stdevfacC <- rep(1, length(inp$obsC))
inp$stdevfacC[1:6] <- 3

c) Moreover, the uncertainty of the survey index for 1983–1990 was also increased.

inp$stdevfacI <- list(c(rep(2, 7), rep(1, length(inp$timeI[[1]]) - 7)))

d) Different runs were conducted setting the prior for the parameter (logn) which determines the shape of the production curve. Three options were tested:

1. Fixing logn=2
2. Fixing initial value of logn=2
3. Using the Tighter Shaefer prior for logn

e) The prior for the initial depletion level (logbkfrac) was also used. There is not an exact knowledge about the exploitation level before the beginning of the available landings data. Nevertheless, *Nephrops* always has been a valuable resource in this area and a target species at the beginning of the time-series. So, it is probably that there was exploitation previously to 1975 at least medium.

f) In order to decrease the confidence intervals of the results, priors for the observation error of (logsdf) and (logsdc) were used in runs 1.1, 2.1 and 3.1. Priors for the ratios of process to observation errors (logalpha) and (logbeta) were removed as it is required.

Table 8.3.1.1 shows the different runs carried out and priors used. The checklist for acceptance of a SPiCT model (Mildenberg *et al.*, 2020) was followed.

Table 8.3.1.1. Runs and priors used related to the shape of the production curve (n), the exploitation level (b/k) and priors for the observation error term of effort and landings.

		RUN 1	RUN 1.1	RUN 2	RUN 2.1	RUN 3	RUN 3.1
SHAPE of the production curve	inp$logn=2	X	X				
	inpinilogn <- log(2); inp$phases$logn <- -1			X	X		
	inp$priors$logn <- c(log(2),0.5,1)					X	X
Initial DEPLETION level prior (B/K)_Medium Level	inp$priors$logbkfrac <-c(log(0.5),1,1)	X	X	X	X	X	X
Others Priors	inp$priors$logalpha <- c(0,0,0)		X		X		X
	inp$priors$logbeta <- c(0,0,0)		X		X		X
	inp$priors$logsdf <- c(log(3), 0.5, 1)		X		X		X
	inp$priors$logsdc <- c(log(0.1), 0.2, 1)		X		X		X

Results

The model did not converge with any combination of the setting priors when **Scenario 1** was tested.

The convergence of the model was found in all runs for **Scenario 2** and **Scenario 3** and stochastics reference points were derived. However, better results were obtained when the logalpha and logbeta priors were removed of the model and logsdf and logsdc priors were applied (RUN 1.2, RUN 2.2 and RUN 3.2).

Nevertheless, the retrospective pattern showed consistence in **Scenario 2** only when a number of years equal to three was used (nretroyear=3). Only retrospective pattern using five years (nretroyear=5) was consistent in RUN1.1. Monh's Rho value never was achieved for **Scenario 3** in any run (See Table 8.3.1.2).

All variance parameters of the model were finite. Regarding to the standard diagnostics, for landings and biomass index, the mean of the one-step-ahead residuals was different from zero, there was not empirical autocorrelation in the residuals, and the residuals were normally distributed. So, no violations of the assumptions of the model were observed for any run for **Scenario 2** and **Scenario 3**.

The shape of the production curve was realistic, with B_{MSY}/K value between 0.5 and 0.7.

The assessment uncertainty analysis showed the confidence intervals for B/B_{MSY} and F/F_{MSY} ranging between 1 and 2 order of magnitude depending on the scenario and run.

Table 8.3.1.2 summaries the checklist for the different scenarios and runs and Table 8.3.1.3 shows model results for exploratory **Scenario 2**. Fit, diagnosis and retrospective plots for the SPiCT model obtained for exploratory **Scenario 2** and RUN X.1 are also included in this report (from Figure 8.3.1.1 to Figure 8.3.1.9).

Stochastic referent points obtained for all runs in **Scenario 2** were similar, as well as the state of stock where $B_{2019}<B_{MSY}$ and $F_{2019}<F_{MSY}$.

Table 8.3.1.2. Checklist of the model for the three scenarios.

	SCENARIO 1 Landings FU26-27 + New combined biomass index for FU26-27					
	RUN 1	**RUN 1.1**	**RUN 2**	**RUN 2.1**	**RUN 3**	**RUN 3.1**
Convergence	No converge	No converge	No converge	No converge	No converge	No converge

	SCENARIO 2 Landings FU26-27 + Stratified biomass index for FU26-27					
	RUN 1	**RUN 1.1**	**RUN 2**	**RUN 2.1**	**RUN 3**	**RUN 3.1**
Convergence	YES	YES	YES	YES	YES	YES
Parameters variance finite	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Model assumption_Diagnosis	OK	OK	OK	OK	OK	OK
Retrospective pattern	OK (retro n=3)	OK	OK (retro n=3)	OK (retro n=3)	OK (retro n=3)	OK (retro n=3)
Monh's Rho (retro -5)						
B/Bmsy	NaN	-0.179	NaN	NaN	NaN	NaN
F/Fmsy	NaN	1.921	NaN	NaN	NaN	NaN
Monh's Rho (retro -3)						
B/Bmsy	-0.123	0.047	-0.155	0.071	-0.151	0.117
F/Fmsy	0.937	0.043	1.048	-0.027	1.002	-0.102
Production curve	0.5	0.7	0.5	0.5	0.5	0.5
Sensitivity to initial values	NULL	NULL	NULL	NULL	NULL	NULL
Uncertainty-order magnitud						
B/Bmsy	2	1	2	1	2	1
F/Fmsy	2	2	2	1	2	1

	SCENARIO 3 Landings FU26-27 + Stratified biomass index for FU26					
	RUN 1	**RUN 1.1**	**RUN 2**	**RUN 2.1**	**RUN 3**	**RUN 3.1**
Convergence	YES	YES	YES	YES	YES	YES
Parameters variance finite	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Model assumption_Diagnosis	OK	OK	OK	OK	OK	OK
Retrospective pattern	Not consistent	Not consistent	Not consistent	Not consistent	Not consistent	Not consistent
Monh's Rho (retro -5)						
B/Bmsy	NaN	NaN	NaN	NaN	NaN	NaN
F/Fmsy	NaN	NaN	NaN	NaN	NaN	NaN
Monh's Rho (retro -3)						
B/Bmsy	NaN	NaN	NaN	NaN	NaN	NaN
F/Fmsy	NaN	NaN	NaN	NaN	NaN	NaN
Production curve	0.49	0.7	0.5	0.5	0.5	0.6
Sensitivity to initial values	NULL	NULL	NULL	NULL	NULL	NULL
Uncertainty-order magnitud						
B/Bmsy	2	1	2	2	2	1
F/Fmsy	3	2	2	1	2	1

NaN: although model fit convergence was achieved some parameters could not be estimated.

Table 8.3.1.3. SPiCT model results for Scenario 2.

Model parameters	**RUN 1**	**RUN 1.1**	**RUN 2**	**RUN 2.1.**	**RUN 3**	**RUN 3.1.**
alpha	3.07	153.69	3.06	46.08	3.06	106.8
beta	0.11	0.18	0.11	0.18	0.11	0.18
r	0.18	0.55	0.16	0.16	0.17	0.3
rc	0.17	0.21	0.16	0.16	0.16	0.21
rold	0.16	0.13	0.16	0.16	0.16	0.16
m	471.24	478.9	464.38	345.36	465.17	417.61
K	10681.21	6646.9	11349.63	8680.05	11273.71	7081.55
q	0	0	0	0	0	0
n	2.11	5.1			2.01	2.85
sdb	0.26	0.01	0.26	0.02	0.26	0.01
sdf	0.42	0.51	0.42	0.51	0.42	0.51
sdi	0.8	0.84	0.8	0.84	0.8	0.84
sdc	0.05	0.09	0.05	0.09	0.05	0.09
Stochastic Reference Points						
Bmsys	4283.93	4466.83	4396.23	4335.09	4383.86	4021.03
Fmsys	0.07	0.11	0.06	0.08	0.07	0.1
MSYs	267.97	478.72	263.68	344.6	264.2	417.42
State						
B_2019.94	269.73	181.84	272.6	192.54	272.28	186.48
F_2019.94	0.04	0.05	0.04	0.05	0.04	0.05
B_2019.94/Bmsy	0.06	0.04	0.06	0.04	0.06	0.05
F_2019.94/Fmsy	0.54	0.48	0.56	0.61	0.55	0.48

Scenario 2. Run 1.1.

inp$logn=2

inp$priors$logbkfrac <-c(log(0.5),1,1)

inp$priors$logalpha <- c(0,0,0)

inp$priors$logbeta <- c(0,0,0)

inp$priors$logsdf <- c(log(3), 0.5, 1)

inp$priors$logsdc <- c(log(0.1), 0.2, 1)

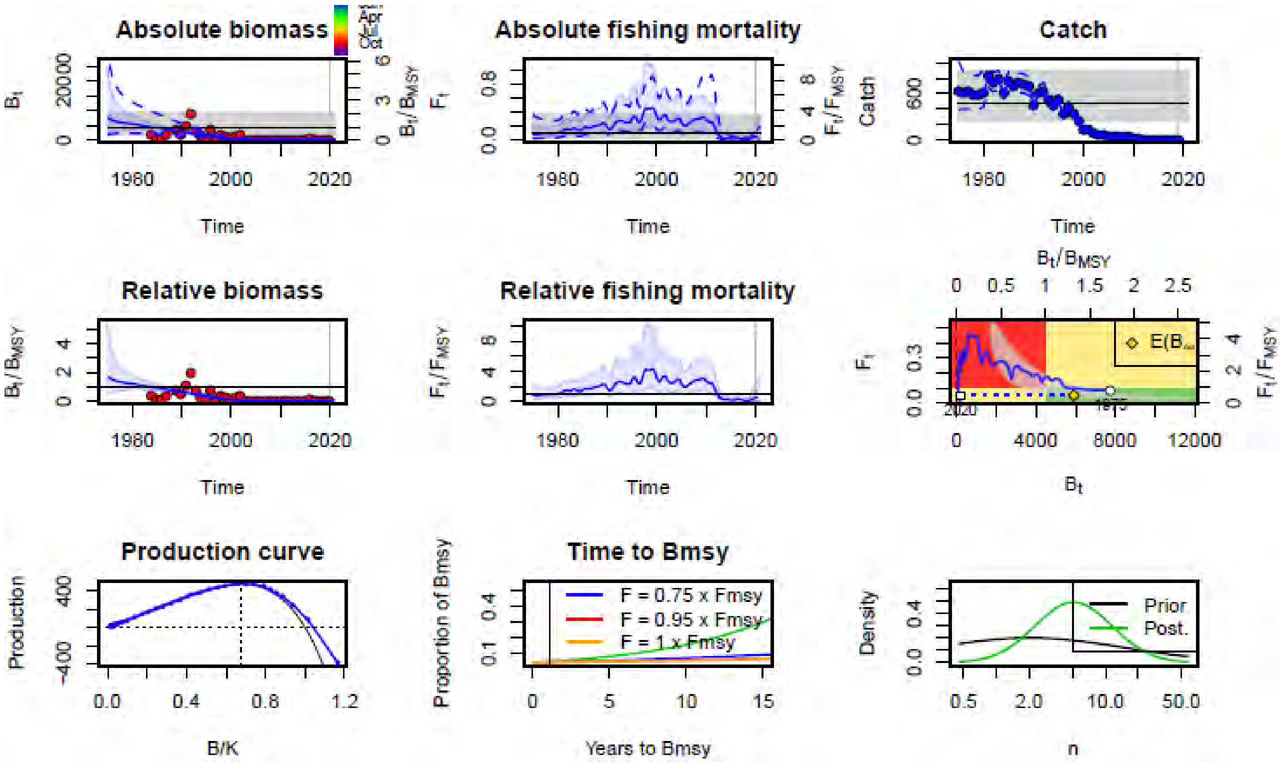


Figure 8.3.1.1. Fit for Scenario 2 and Run 1.1.

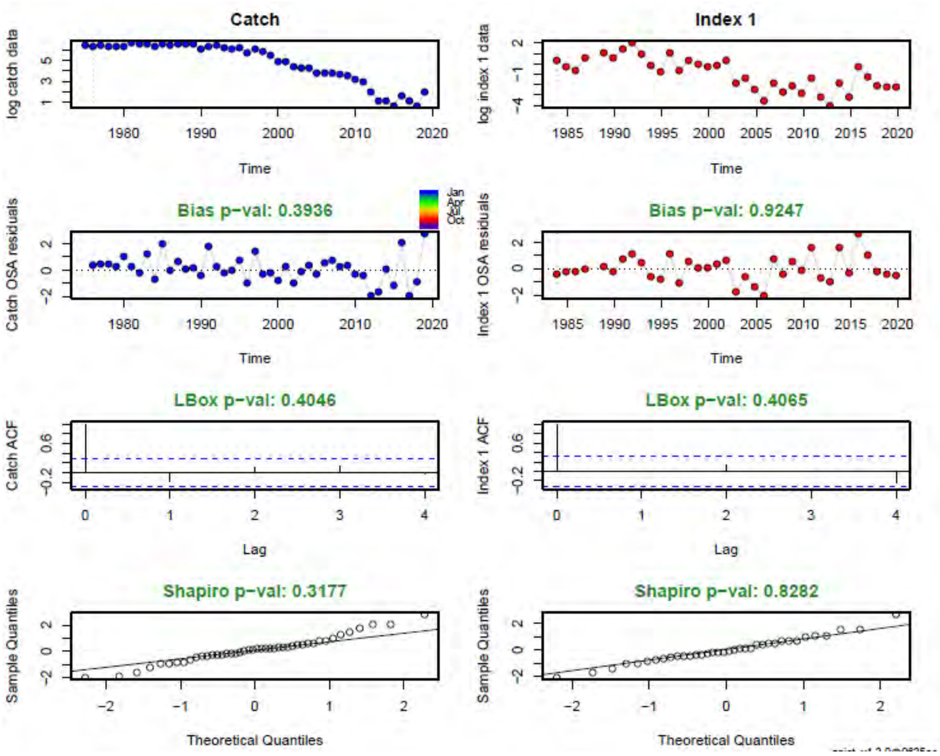
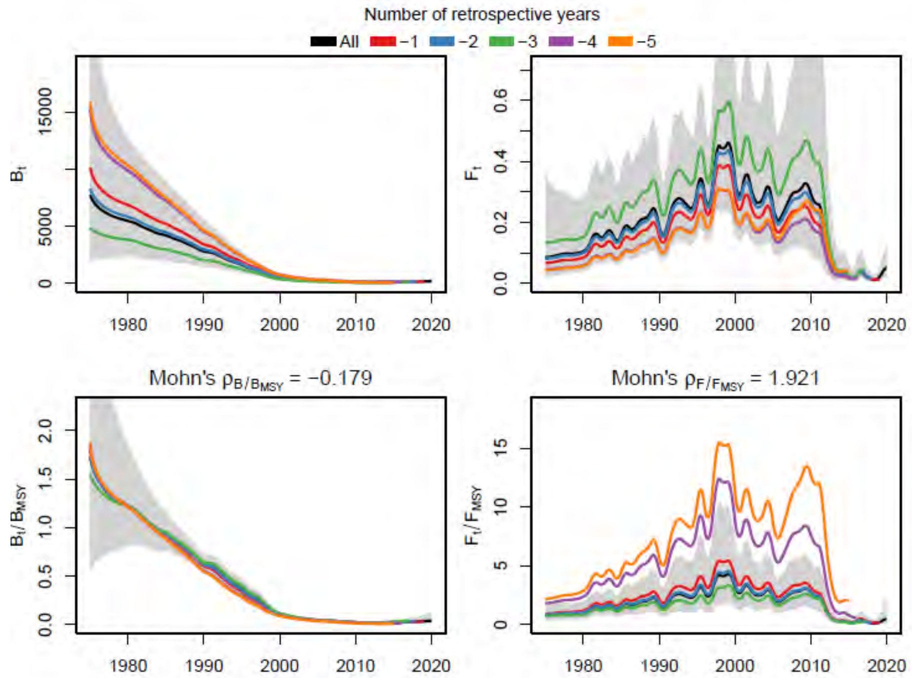


Figure 8.3.1.2. Diagnostics for Scenario 2 and Run 1.1.



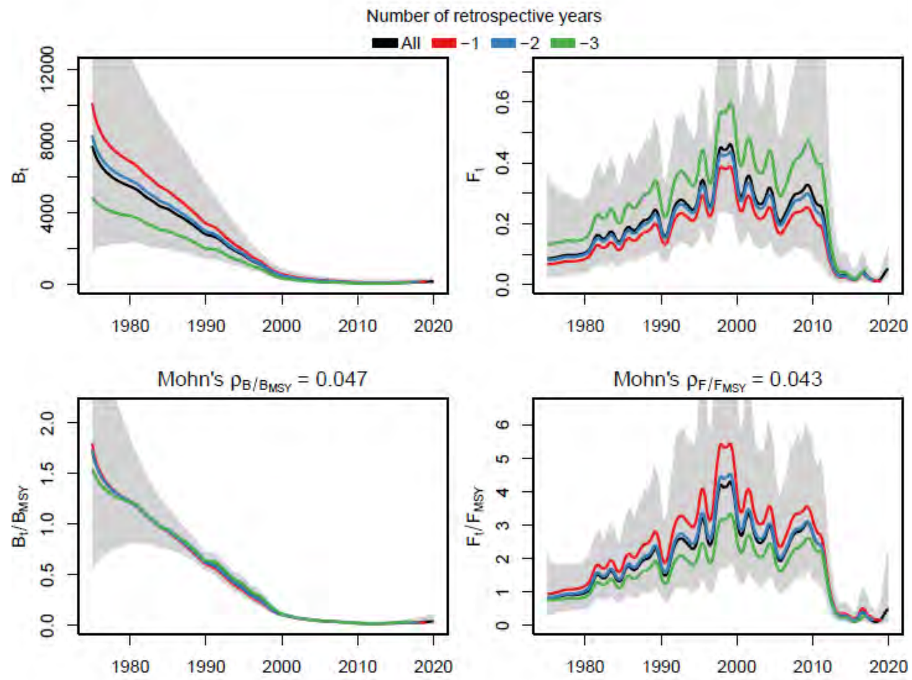


Figure 8.3.1.3. Retrospective pattern for Scenario 2 and Run 1.1. (Above) nretroyear=5; (below) nretroyear=3.

Scenario 2. Run 2.1.

inpinilogn <- log(2); inp$phases$logn<-1inp$priors$logbkfrac <-c(log(0.5),1,1)

inp$priors$logalpha <- c(0,0,0)

inp$priors$logbeta <- c(0,0,0)

inp$priors$logsdf <- c(log(3), 0.5, 1)

inp$priors$logsdc <-c(log(0.1), 0.2, 1)

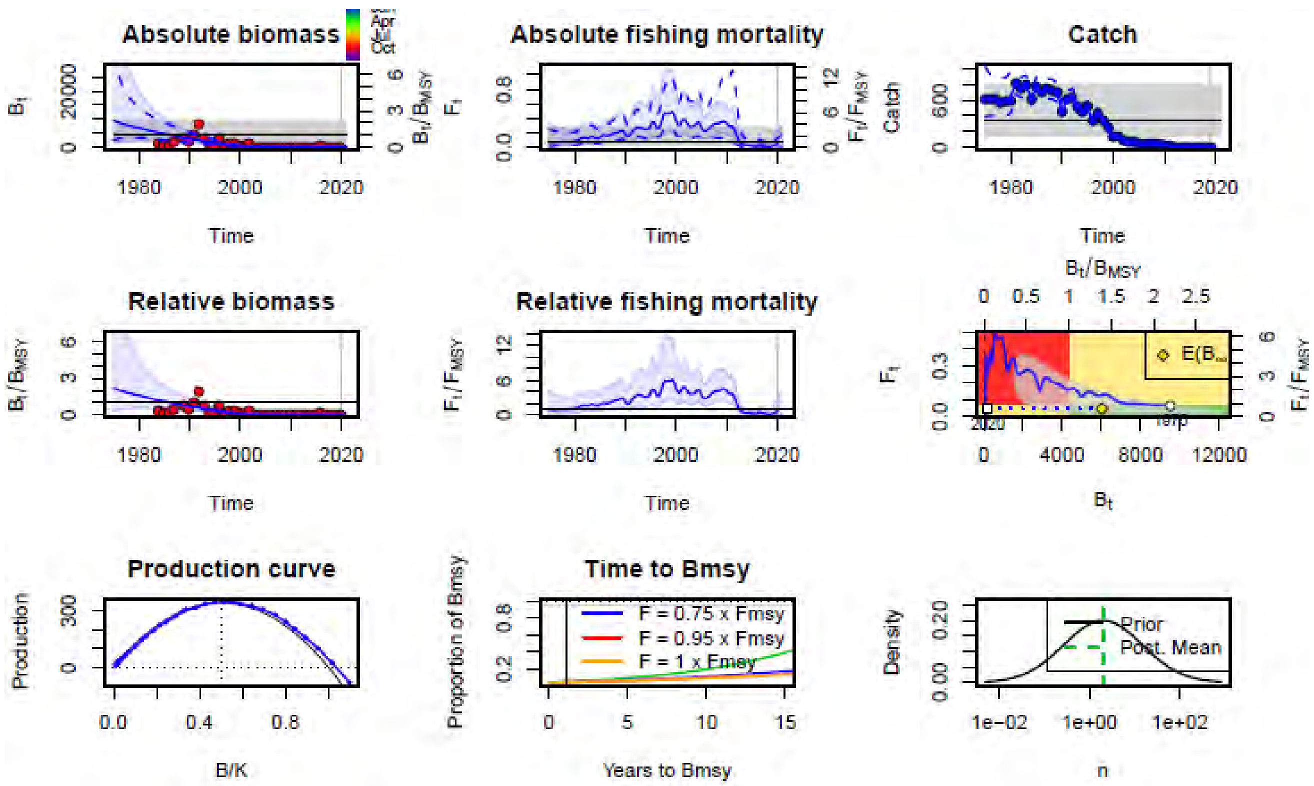


Figure 8.3.1.4. Fit for Scenario 2 and Run 2.1.

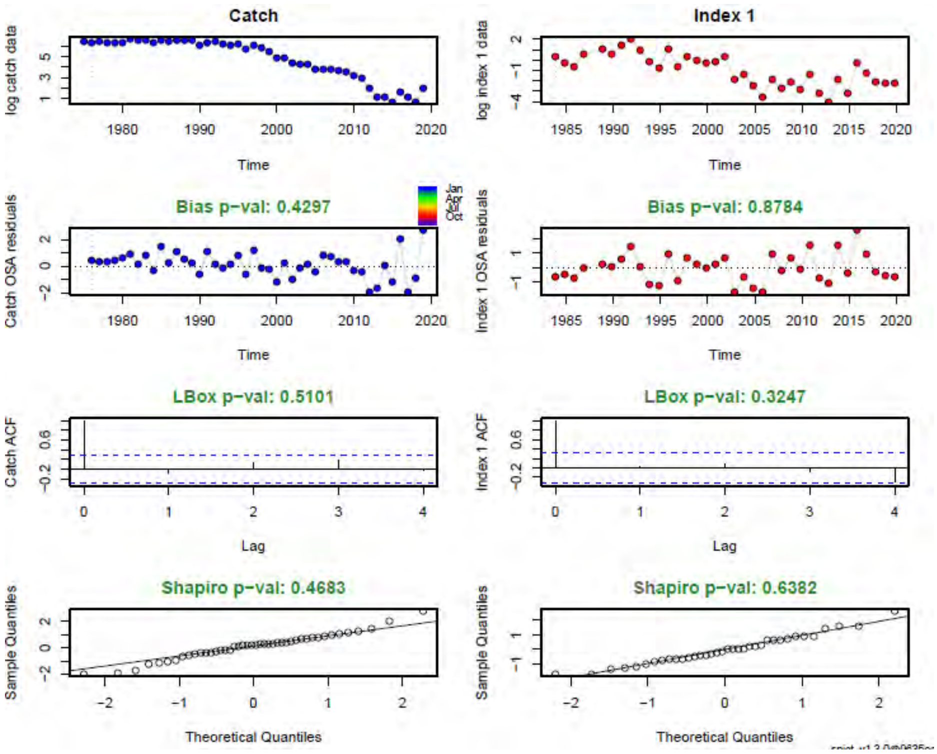


Figure 8.3.1.5. Diagnostics for Scenario 2 and Run 2.1.

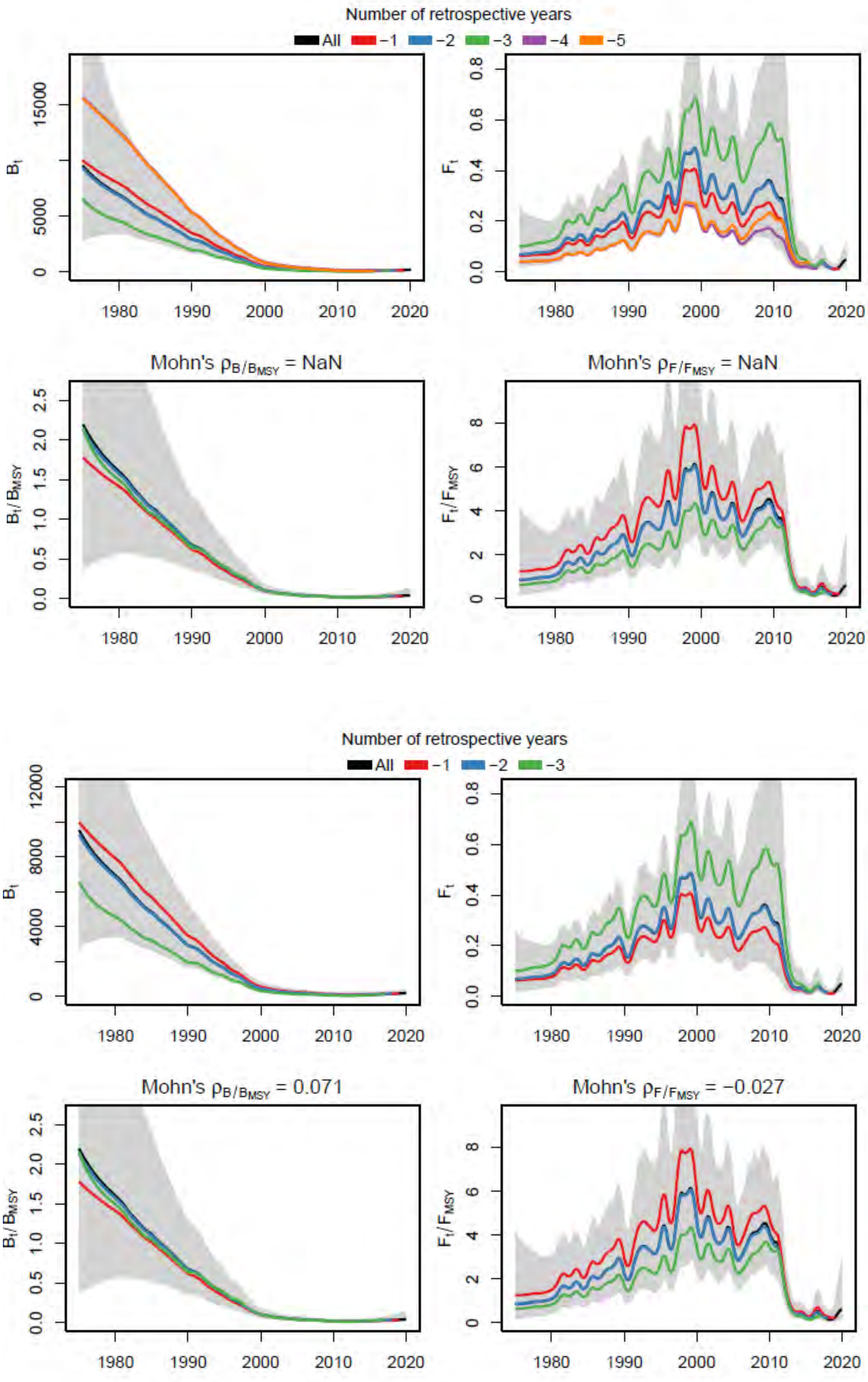


Figure 8.3.1.6. Retrospective pattern for Scenario 2 and Run 2.1. (Above) nretroyear=5; (below) nretroyear=3.

Scenario 2. Run 3.1.

inp$priors$logn <- c(log(2),0.5,1)

inp$priors$logbkfrac <-c(log(0.5),1,1)

inp$priors$logalpha <- c(0,0,0)

inp$priors$logbeta <- c(0,0,0)

inp$priors$logsdf <- c(log(3), 0.5, 1)

inp$priors$logsdc <-c(log(0.1), 0.2, 1)

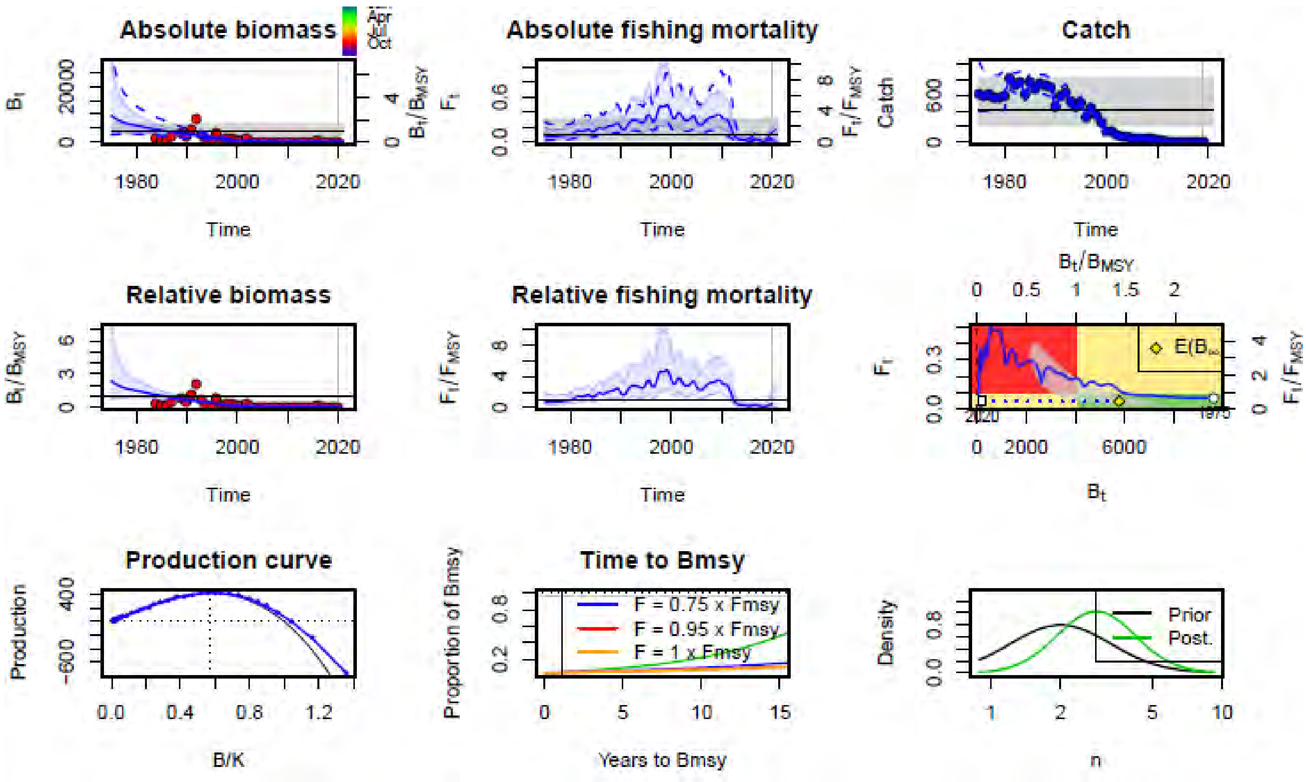


Figure 8.3.1.7. Fit for Scenario 2 and Run 3.1.

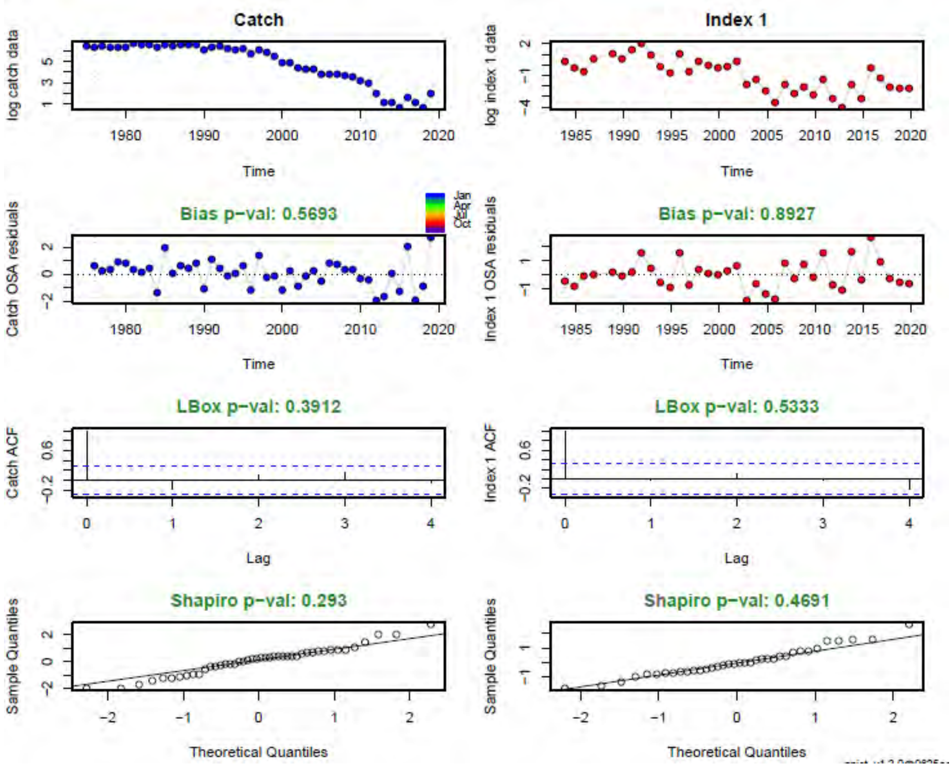


Figure 8.3.1.8. Diagnostics for Scenario 2 and Run 3.1.

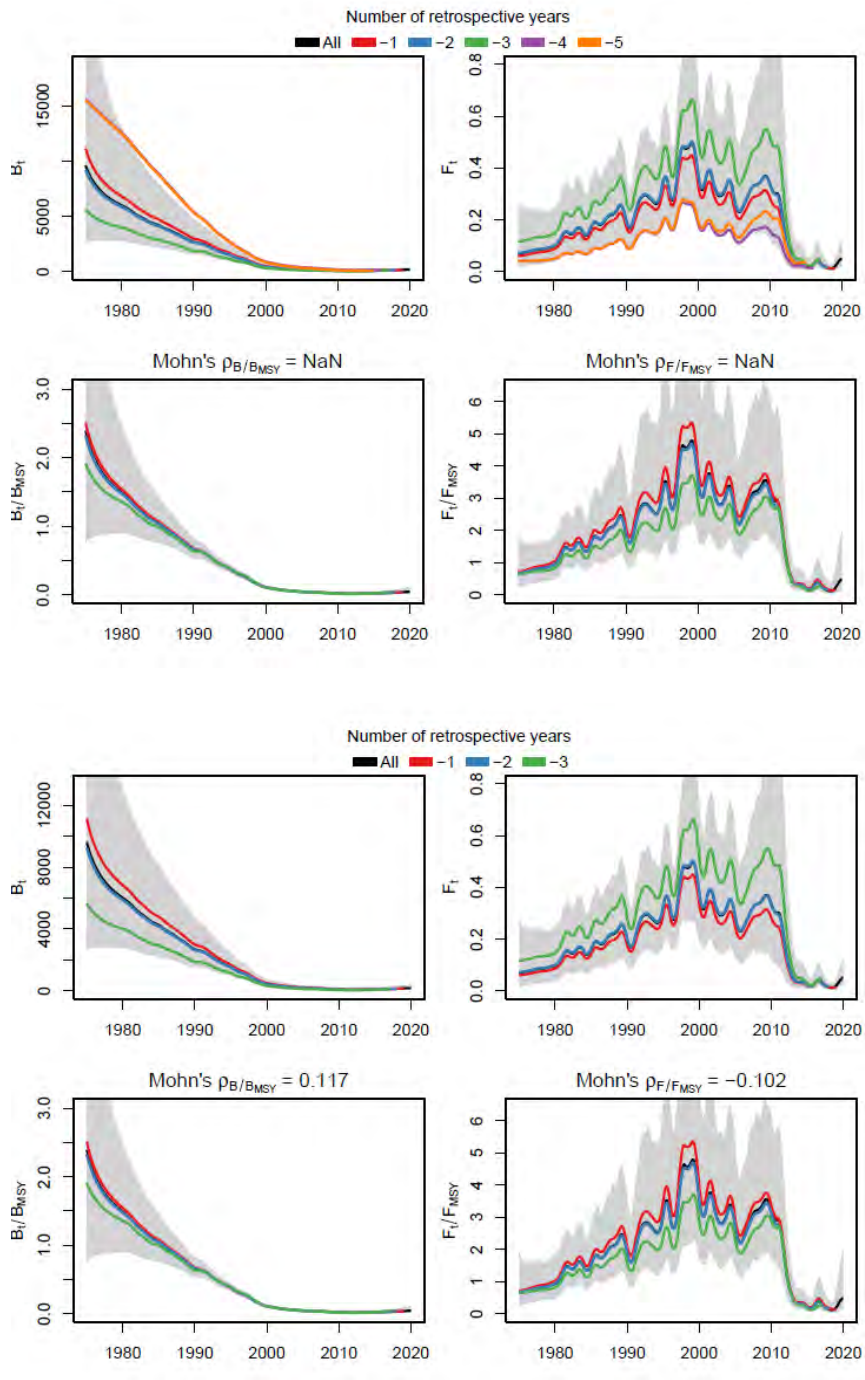


Figure 8.3.1.9. Retrospective pattern for Scenario 2 and Run 3.1. (Above) nretroyear=5; (below) nretroyear=3.

Two extra runs based on the Run 3.1 in the Scenario 2 were carried out during the Benchmark Workshop according to suggestions done by the experts. Below is shown the new configurations tested:

Extra run 1	**Extra run 2**
Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)	Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)
Inp$priors$logr <- c(log(0.2), 0.2, 1)	Inp$priors$logr <- c(log(0.2), 0.2, 1)
	Inp$priors$logn <- c(log(2), 0.5, 1)
Inp$priors$logalpha <- c(log(0, 0, 0)	Inp$priors$logalpha <- c(log(0, 0, 0)
Inp$priors$logbeta <- c(log(0, 0, 0)	Inp$priors$logbeta <- c(log(0, 0, 0)
Inp$priors$logsdf <- c(log(3), 0.5, 1)	Inp$priors$logsdf <- c(log(3), 0.5, 1)
Inp$priors$logsdc <- c(log(0.1), 0.2, 1)	Inp$priors$logsdc <- c(log(0.1), 0.2, 1)

In this stock, *Nephrops* landings at the beginning of the time-series are close to the maximum value recorded during the time-series and it was not possible to reconstruct historical catches in order to know the exploitation level before. In these cases, it was recommended to set the initial biomass depletion level, b/k prior, to 0.5 with a low CV. In previous exploratory runs, logbkfrac was set to 0.5 but the CV was set to 1, higher than CV recommended (0.2). The prior for intrinsic growth rate (r) was set to 0.2 with a low CV in order to increase model stability. In Extra run 2, the prior for production curve n was included in the model configuration, using the Tighter Shaefer prior.

A sensitivity analysis of b/k prior was also conducted to evaluate the fits, retrospective pattern and predictions skill. Values lower and higher of 0.5 were used in this sensitivity analysis "(Inp$priors$logbkfrac <- c(log(0.3), 0.2, 1), Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1) and Inp$priors$logbkfrac <- c(log(0.7), 0.2, 1)". The sensibility analysis results for Extra run 1 and Extra run 2 are shown in Table 8.3.1.4. Extra run 1 and Extra run 2 found the requirement to accept the models (Table 8.3.1.5). The fit, diagnostics and retrospective pattern plots for Extra run 1 and Extra run 2 with medium initial depletion level are shown from Figure 8.3.1.10 to Figure 8.3.1.15.

Table 8.3.1.4. Sensitivity analysis for b/k prior for EXTRA RUN 1 and EXTRA RUN 2.

	EXTRA RUN 1			EXTRA RUN 2		
	b/k medium level	b/k high level	b/k low level	b/k medium level	b/k high level	b/k low level
	bkfrac_(0.5,0.2,1)	bkfrac_(0.7,0.2,1)	bkfrac_(0.3,0.2,1)	bkfrac_(0.5,0.2,1)	bkfrac_(0.7,0.2,1)	bkfrac_(0.3,0.2,1)
Model Parameters						
alpha	58.89	72.4	49.05	59.17	72.53	48.63
beta	0.18	0.18	0.18	0.18	0.18	0.18
r	0.2	0.2	0.2	0.2	0.2	0.19
rc	0.16	0.16	0.15	0.17	0.17	0.17
rold	0.14	0.14	0.12	0.15	0.15	0.15
m	516.06	431.91	762.95	516.1	436.4	736.24
K	11750.54	9803.75	18485.36	11402.85	9595.74	16743.89
q	0	0	0	0	0	0
n	2.42	2.46	2.63	2.27	2.3	2.33
sdb	0.01	0.01	0.02	0.01	0.01	0.02
sdf	0.51	0.51	0.51	0.51	0.51	0.51
sdi	0.84	0.84	0.84	0.84	0.84	0.84
sdc	0.09	0.09	0.09	0.09	0.09	0.09
Reference Points						
Bmsys	6298.99	5288.05	10199.06	5978.53	5056.12	8853.12
Fmsys	0.08	0.08	0.07	0.09	0.09	0.08
MSYs	515.25	431.46	760.91	515.39	435.99	734.65
State						
B_2019.94	184.72	185.45	182.04	186.39	187.3	183.98
F_2019.94	0.05	0.05	0.05	0.05	0.05	0.05
B_2019.94/Bmsy	0.03	0.04	0.02	0.03	0.04	0.02
F_2019.94/Fmsy	0.61	0.61	0.68	0.58	0.58	0.61
Predictions						
B_2021.00	203.04	203.44	196.06	207.98	208.7	203.45
F_2021.00	0.05	0.05	0.05	0.05	0.05	0.05
B_2021.00/Bmsy	0.03	0.04	0.02	0.03	0.04	0.02
F_2021.00/Fmsy	0.61	0.61	0.68	0.58	0.58	0.61
Catch_2020.00	9.72	9.71	9.56	9.83	9.83	9.76
E(B_inf)	8563.53	7183.75	13178.75	8366.63	7081	12120.07

Table 8.3.1.5. Checklist for sensitivity analysis b/k prior for EXTRA RUN 1 and EXTRA RUN 2.

	EXTRA RUN 1			EXTRA RUN 2		
	b/k medium level	b/k high level	b/k low level	b/k medium level	b/k high level	b/k low level
	bkfrac_(0.5,0.2,1)	bkfrac_(0.7,0.2,1)	bkfrac_(0.3,0.2,1)	bkfrac_(0.5,0.2,1)	bkfrac_(0.7,0.2,1)	bkfrac_(0.3,0.2,1)
Convergence	YES	YES	YES	YES	YES	YES
Parameters variance finite	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Model assumption_Diagnosis	OK	OK	OK	OK	OK	OK
Restropective pattern						
Monh's Rho (retro -5)						
F/Fmsy	1.036	0.502	1.282	0.299	0.301	0.329
B/Bmsy	-0.238	-0.164	-0.344	-0.112	-0.112	-0.133
Realistic production curve	0.54	0.54	0.55	0.52	0.53	0.53
Sensitivity to initial values	OK	OK	OK	OK	OK	OK
Assessment uncertainty						
F/Fmsy	1	1	1	0	1	1
B/Bmsy	1	0	1	1	0	1

Extra run 1

Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)

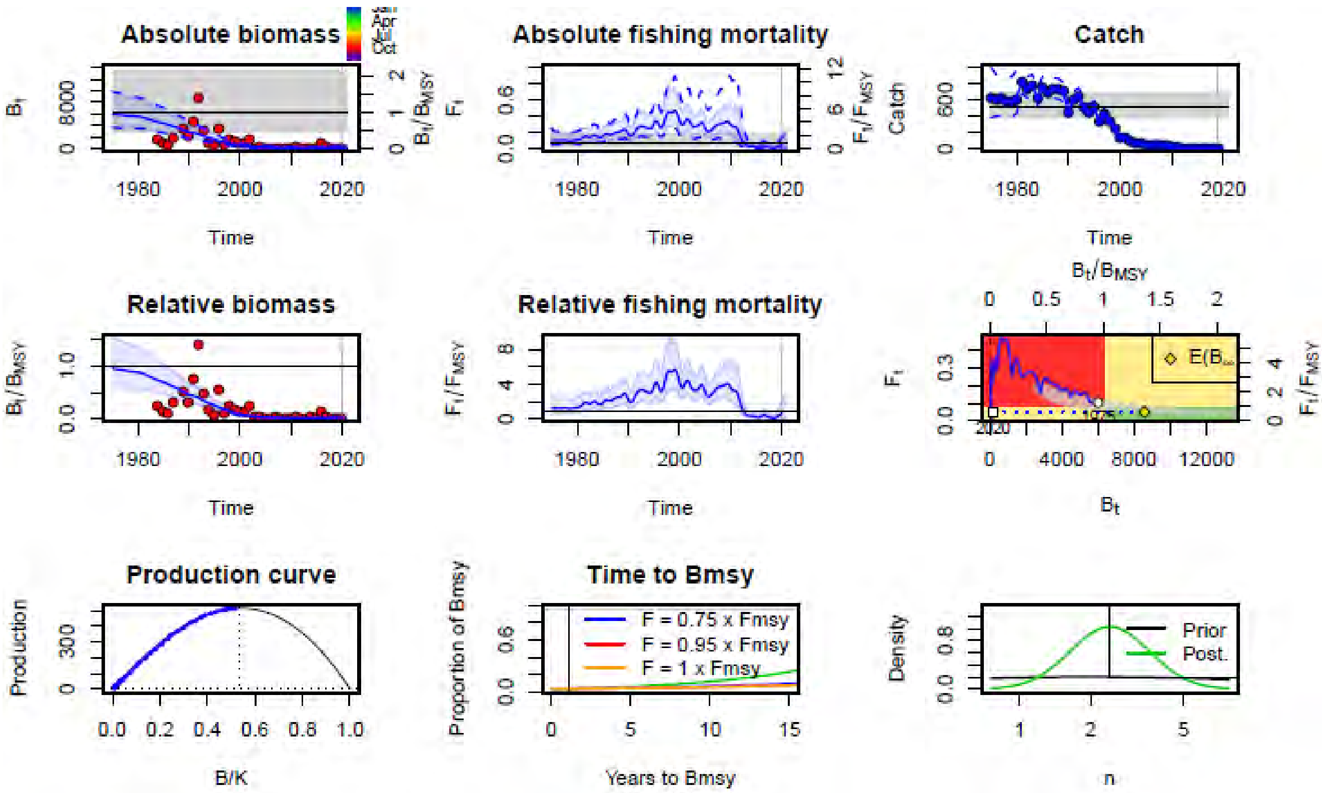


Figure 8.3.1.10. Fit for EXTRA RUN 1 and medium initial depletion level.

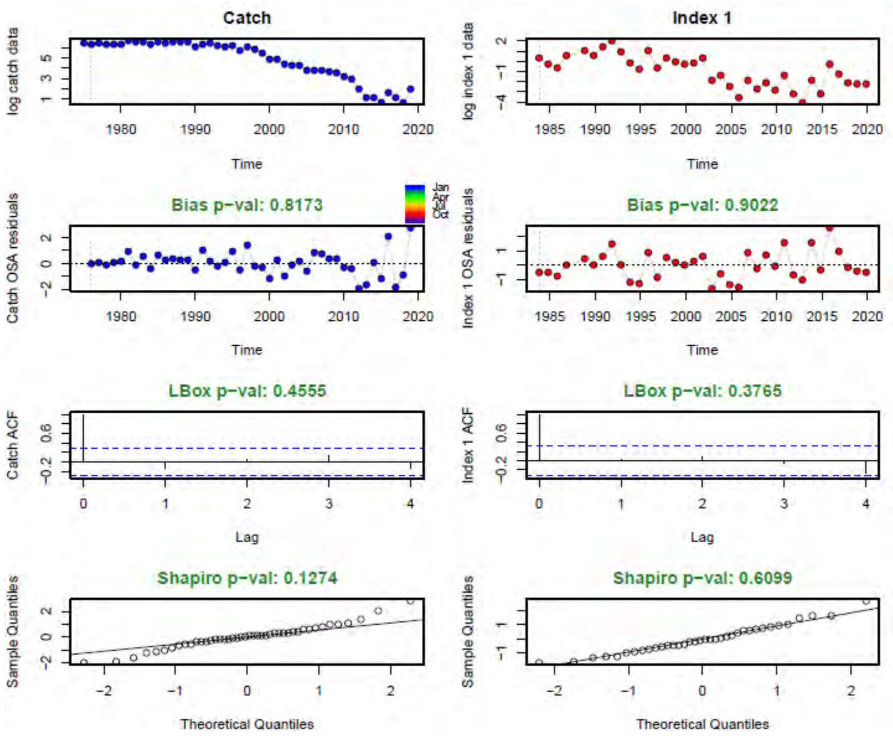


Figure 8.3.1.11. Diagnostics for EXTRA RUN 1 and medium initial depletion level.

Extra run 1

Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)

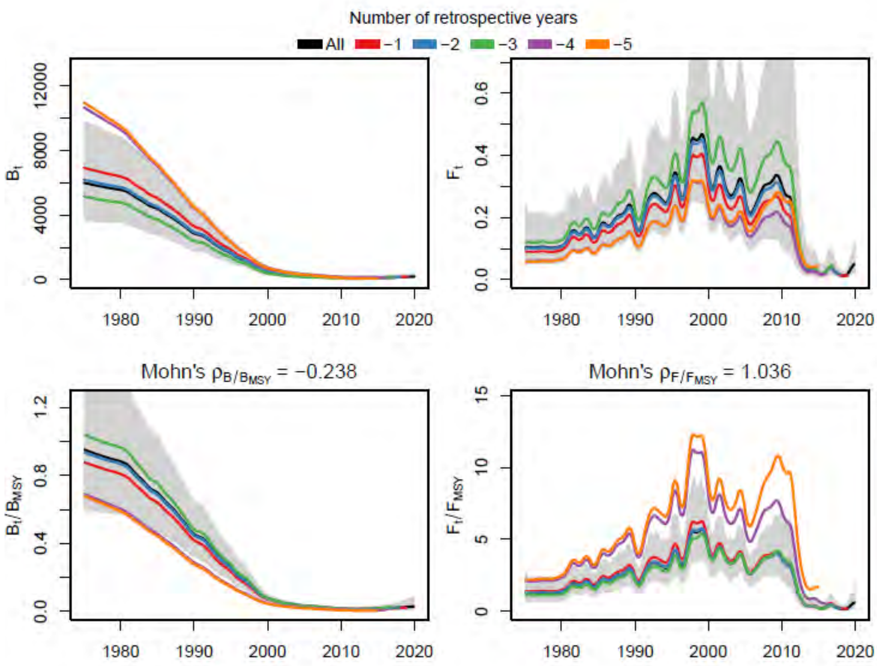


Figure 8.3.1.12. Retrospective pattern for EXTRA RUN 1 with low initial depletion level.

Extra run 2

Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)

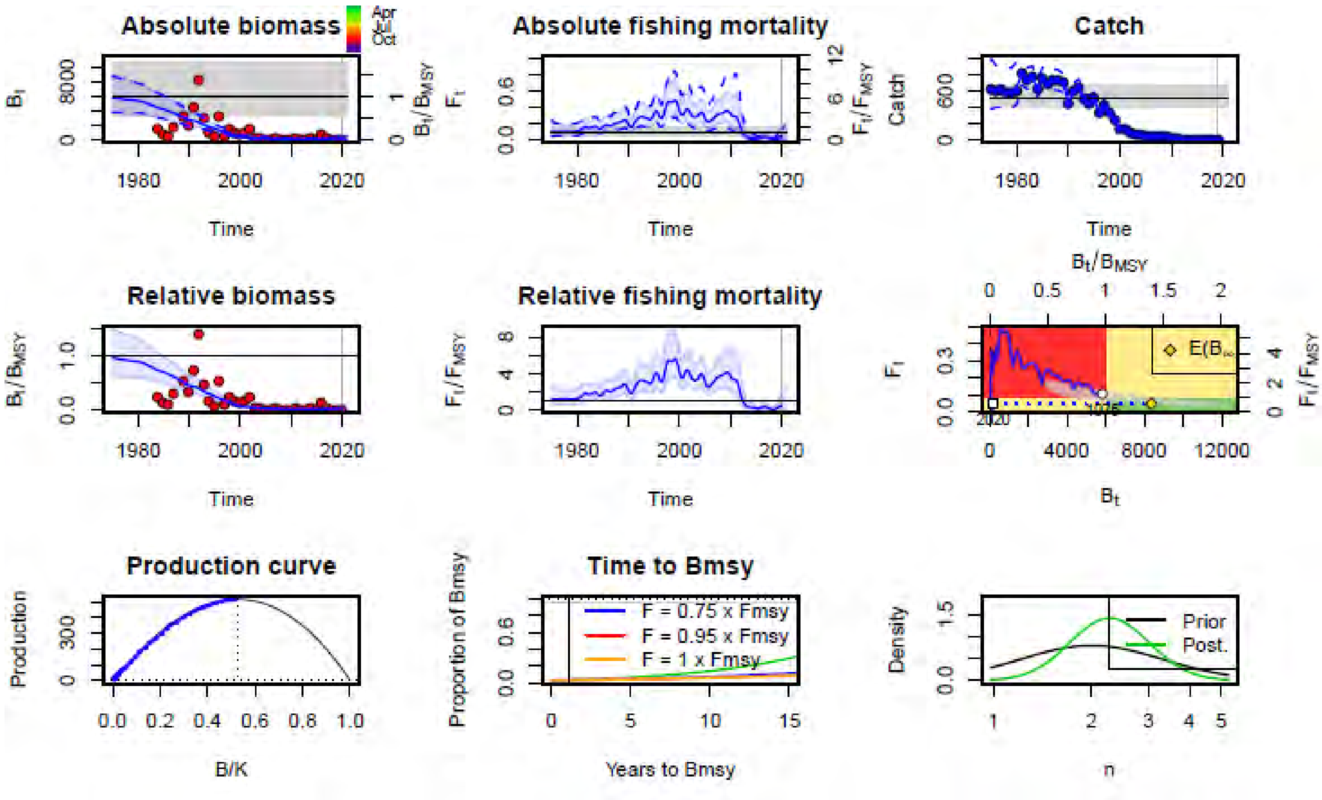


Figure 8.3.1.13. Fit for EXTRA RUN 2 and medium initial depletion level.

Extra run 2

Inp$priors$logbkfrac <- c(log(0.5), 0.2, 1)

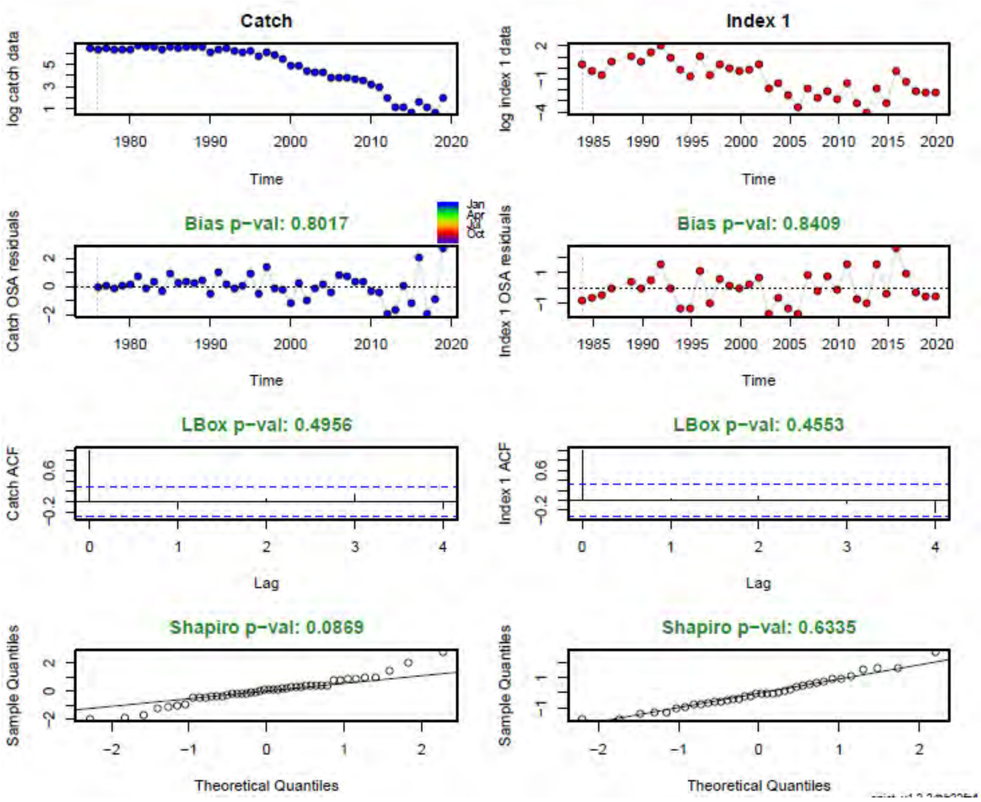


Figure 8.3.1.14. Diagnostics for EXTRA RUN 2 and medium initial depletion level.

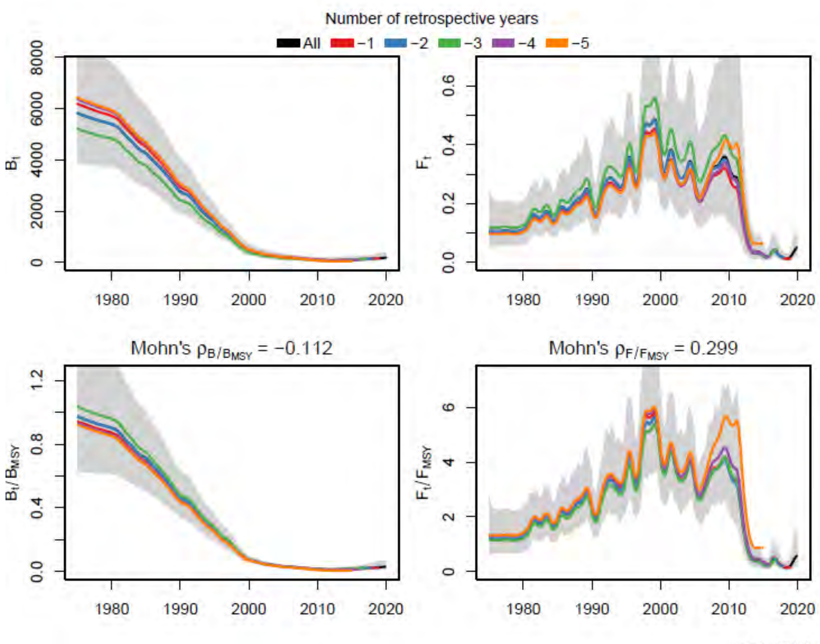


Figure 8.3.1.15. Retrospective pattern for EXTRA RUN 2 and medium initial depletion level.

8.3.2 Final assessment

The configuration of the SPiCT model chosen for the *Nephrops* in FU26-27 assessment was Extra run 2 with medium initial depletion level. Fit, diagnostic and retrospective pattern are shown in Figures 8.3.1.13, 8.3.1.14 and 8.3.1.15, respectively. Results of the model are shown in Table 8.3.2.1. Below is shown the R code used:

```
## Scale index to mean 1 (for better numerical stability)
mstd <-function(x) x/mean(x,na.rm=TRUE)
data$DEM = mstd(data$DEM)

## CREATE THE inp OBJECT FOR THE MODEL
inp <- list(timeC=data$TC, obsC=data$C,
        obsI=list(obsI=data$DEM),
        timeI=list(timeI=data$TDEM+0.8333333))
inp$dteuler=1/16 ## Obs, this needs to be set BEFORE calling check.inp
inp=check.inp(inp)
inp$dtc

##Check list
check.inp(inp)

## Extra uncertainty in 1975-1980 period Catch
inp$stdevfacC <- rep(1, length(inp$obsC))
inp$stdevfacC[1:6] <- 3

## Extra uncertainty in 1983-1990 period survey index
inp$stdevfacI <- list(c(rep(2, 7), rep(1, length(inp$timeI[[1]]) - 7)))

##To increase n.iter
inp$optimiser.control= list(iter.max = 1e6, eval.max = 1e6)

## Setting priors
inp$priors$logbkfrac <-c(log(0.5),0.2,1) ## Initial DEPLETION level prior (B/K)_medium level
inp$priors$logr <-c(log(0.2),0.2,1) ### r Prior
inp$priors$logn <- c(log(2),0.5,1) ## SHAPE of the Shaefer production curve (Tighter Shaefer prior)
inp$priors$logalpha <- c(0,0,0)   # deactivate
inp$priors$logbeta <- c(0,0,0)   # deactivate
inp$priors$logsdf <- c(log(3), 0.5, 1) # decrease F sd
inp$priors$logsdc <- c(log(0.1), 0.2, 1) # Control catch error sd
```

Nephrops landings in FU26–27 decreased more than 95% along time-series and the biomass index indicates an extremely low biomass since 2000's. Spatial analysis of the biomass index shows a reduction of the historical *Nephrops* distribution in these stocks. Fishing mortality in the last year of the time-series is below fishing mortality at MSY (F_{2019}/F_{msy}=0.58) and biomass in 2019 is also below biomass at MSY (B_{2019}/B_{msy}=0.03).

Table 8.3.2.1. SPiCT model results for the final assessment (EXTRA RUN 2, b/k (0.5, 0.2, 1)).

Model Parameters	estimate	cilow	ciupp	log.est
alpha	59.17	0.08	43777.3	4.08
beta	0.18	0.11	0.3	-1.7
r	0.2	0.13	0.29	-1.63
rc	0.17	0.1	0.31	-1.76
rold	0.15	0.06	0.4	-1.87
m	516.1	394.23	675.65	6.25
K	11402.85	7334.76	17727.23	9.34
q	0	0	0	-7.01
n	2.27	1.31	3.93	0.82
sdb	0.01	0	10.42	-4.26
sdf	0.51	0.39	0.66	-0.68
sdi	0.84	0.66	1.06	-0.18
sdc	0.09	0.06	0.13	-2.38
Reference Points	estimate	cilow	ciupp	log.est
B_{MSY}s	5978.53	3345.75	10683.08	8.7
F_{MSY}	0.09	0.05	0.16	-2.45
MSYs	515.39	393.84	674.44	6.24
State	estimate	cilow	ciupp	log.est
B_2019.94	186.39	85.98	404.04	5.23
F_2019.94	0.05	0.02	0.12	-3
B_2019.94/B_{MSY}	0.03	0.01	0.09	-3.47
F_2019.94/F_{MSY}	0.58	0.19	1.76	-0.55

8.4 Catch forecast (ToR 4)

Catch forecast was carried out using SPiCT version 1.3.4 and R code presented during the Benchmark Workshop. Forecast was conducted using Fsq for the intermediate year. Results for the four different scenarios agreed in the Benchmark Workshop are shown in Table 8.4.1. Management plots and harvest control rules plots are also presented in Figures 8.4.1 and 8.4.2, respectively.

Table 8.4.1. Catch forecast for different scenarios.

```
SPiCT timeline:
```

Observations	Intermediate	Management
1975.00 - 2020.00	2020.00 - 2021.00	2021.00 - 2022.00

|----------------------| ---------------------| ---------------------|

Management evaluation: 2022.00

Predicted catch for management period and states at management evaluation time:

		Catch	B/Bmsy	F/Fmsy	B	F	perc.dB	perc.dF
1. No Fishing Option	F=0	0	0.04	0	236.8	0	17.5	-100
2. Fishing at Status Quo	F=Fsq	10.9	0.04	0.59	225	0.05	11.7	0
3. ICES Jockey Stick	F=Fmsy	0	0.04	0	236.8	0	17.5	-100
4. 35th Percentile on the Catch	F=Fmsy_C_fractile	0	0.04	0	236.8	0	17.5	-100

95% confidence intervals for states:

		B/Bmsy.lo	B/Bmsy.hi	F/Fmsy.lo	F/Fmsy.hi	B.lo	B.hi	F.lo	F.hi
1. No Fishing Option	F=0	0.01	0.14	0	0	96.1	583.7	0	0
2. Fishing at Status Quo	F=Fsq	0.01	0.14	0.1	3.61	87.7	577.5	0.01	0.28
3. ICES Jockey Stick	F=Fmsy	0.01	0.14	0	0	96.1	583.7	0	0
4. 35th Percentile on the Catch	F=Fmsy_C_fractile	0.01	0.14	0	0	96.1	583.7	0	0

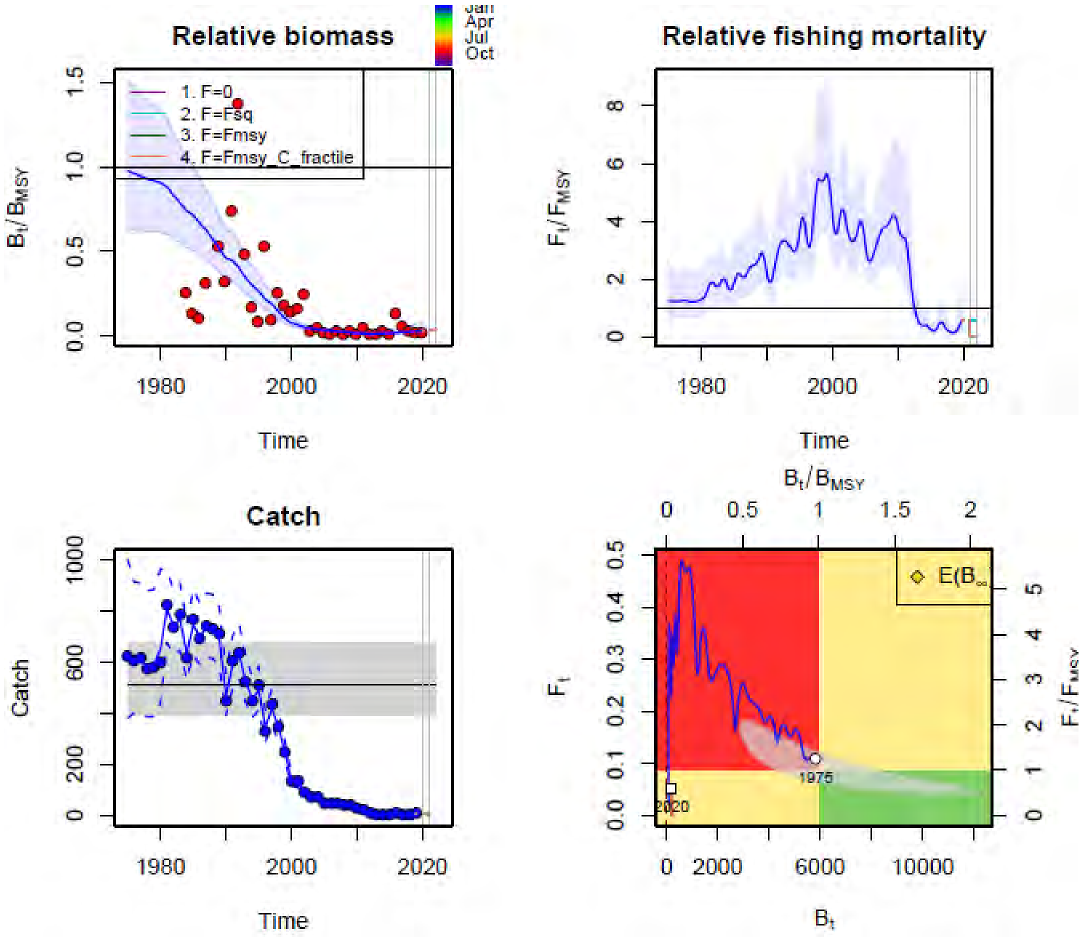


Figure 8.4.1. Catch, relative biomass, relative fishing mortality and Kobe plots for *Nephrops* FU26–27.

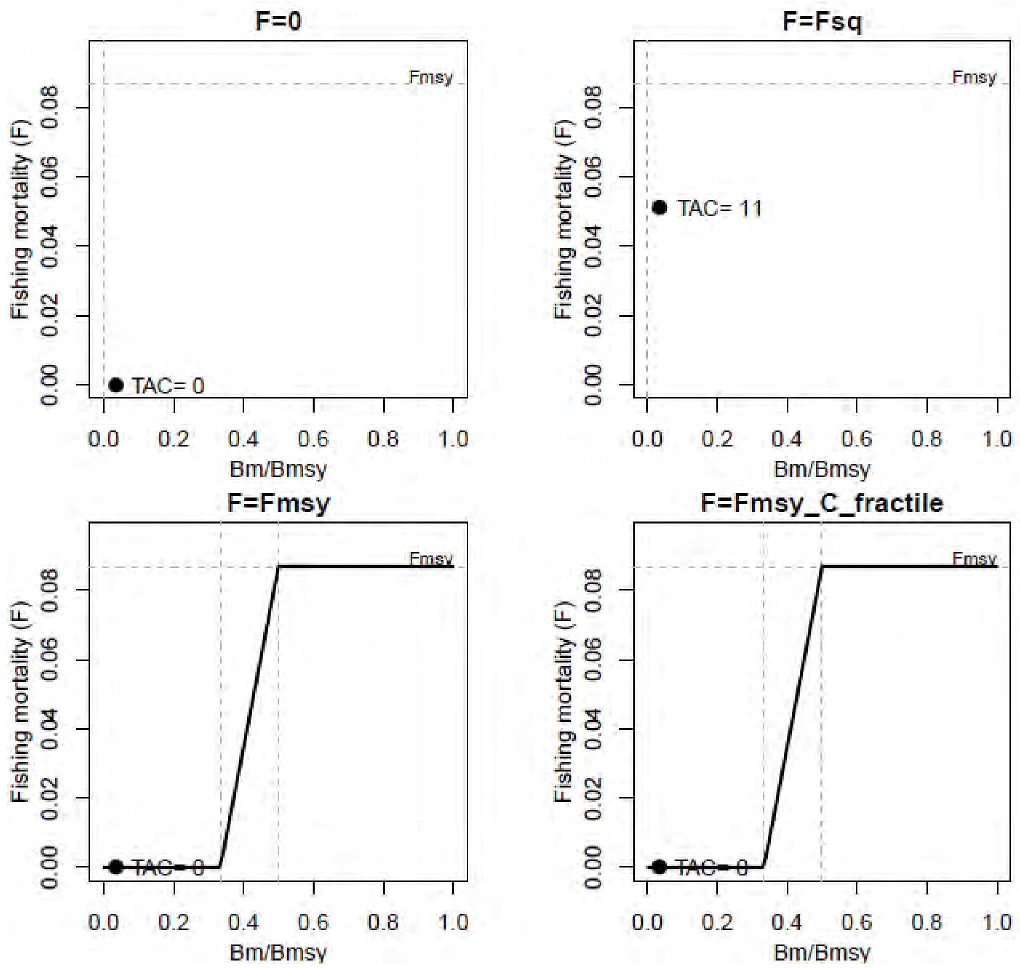


Figure 8.4.2. Harvest control rules plots for different scenarios for *Nephrops* FU26–27.

8.5 Future considerations/recommendations

The combined biomass index for *Nephrops* in FU26–27 stock obtained by the Bayesian hierarchical model in this Benchmark Workshop did not find the convergence requirements. The model configuration could not be improved during this meeting for lack of time. However, further analysis in this sense is recommended.

Data by haul from the International Bottom Trawl Surveys (IBTS) conducted in FU26 (Western Galicia) **(SP-NSGFS-Q4 IBTS)** and in FU 27 (North of Portugal) **(PtGFS-WIBTS-Q4)** must be submitted by the national institutes to WGBIE in order to update de biomass index used as input in the SPiCT model.

8.6 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

Similar to *Nephrops* FU 25 and in FU 31 assessments, the stock assessment of FUs 26&27 is based on a relatively long catch time-series and two survey indices. The trends in both catches series and surveys are consistent with a depleted stock. A newly initiated commercial CPUE index is also available, but with only two years of data, these were not considered for the assessment.

Following the data meeting recommendations, only surveys were used. The surveys were standardized including depth as an additional variable and putative fishing grounds to account for spatial effect (i.e. fishing sectors). The survey indices were combined to derive a single CPUE time-series for the stock in FUs 26&27. The procedure is well described but, as for other stocks, a spatial-time interaction factor is not included in the model. Spatio-temporal differences in abundance linked to environmental changes and/or depletion implies that the use of spatio-temporal models for standardizing fisheries-dependent CPUE data will be increasingly necessary in the future. The model-based index used an autoregressive process to estimate the time-trend (years). This implies that the resulting indices by year are not independent of each other, and the time-series will appear smoother as opposed to when year effects are treated independently. This is undesirable when the index is used as data in an assessment model that assumes that each datapoint is independent of the others. It is therefore recommended to use independent year effects in model-based approaches.

Nonetheless, exploratory SPiCT assessments using the new combined model-based index were performed, but model convergence could not be achieved with the new index for any of the runs tried. Hence, a simpler approach was chosen to combine the two survey indices (based on area and depth stratified arithmetic means). Model convergence was achieved using the second approach.

The estimates of uncertainty are smaller for this stock and all the different model configurations estimate a nearly pristine stock in the start of the time-series. However, catches peaked at the start of the time-series, which most likely implies that the fishery has started long before 1983.

It was therefore suggested to perform an alternative model configuration, constraining the b/k ratio prior to be much lower than 1. Accordingly, alternative model runs with lower b/k prior means of 0.5 were evaluated. Although these produced slightly improved model diagnostics, parameter uncertainty still remained relatively large, the runs showed undesirable retrospective patterns, and the stock at the start of the time-series were still estimated to be close to pristine, which does not match the history of the fishery. Therefore, alternative runs were requested at the benchmark meeting with a tighter prior on the b/k ratio (logbkratio = c(log(0.5),0.2,1). In addition, an extra prior on the intrinsic growth rate 'r' was imposed (mean=0.2 and CV=0.2) in line with what was done for the other *Nephrops* stocks. Sensitivity runs assuming different values for the prior on the initial depletion level were performed, and while the estimated initial depletion level is sensitive to the choice of this prior, the estimated stock status in the final year was found to be much less sensitive to this assumption.

Conclusions

The results were corroborating the previous configurations and thus run2 was agreed as the base-case model for providing advice for FU 26&27. The stronger priors imposed in extra run2 improves the retrospective on B/B_{MSY} and thus extra run2 was considered as the final model for providing advice.

8.7 References

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9 Norway lobster (*Nephrops norvegicuss*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay, North Galicia) (nep.fu.25)

9.1 Introduction

Nephrops Functional Unit (FU) 25 (North Galicia) extends among Finisterre and Ortegal Capes in the Northwest of Spain (ICES Division 8c, Figure 9.1).

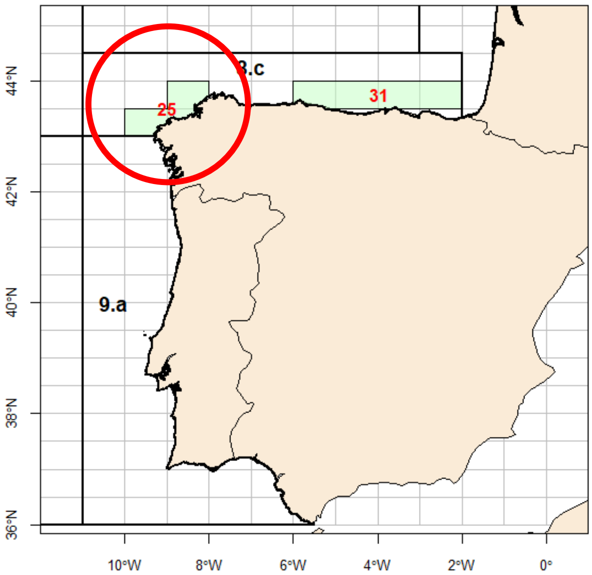

Figure 9.1. FU 25 *Nephrops*. Allocation in Division 8.c. FU 25 covers statistical rectangles 15E0-E1 and 16E1.

The species is mostly a bycatch of the bottom trawl fleet that targets hake, megrim and monkfish in the area. The exploitation of the FU 25 stock affects the conservation of the large size individuals, which are the most efficient in terms of reproduction. FU 25 *Nephrops* catch has decreased a 98% since 1975 to 2016 (Figure 9.2) (ICES, 2020) and there has also been a contraction of the stock area of 71% (Figure 9.3).

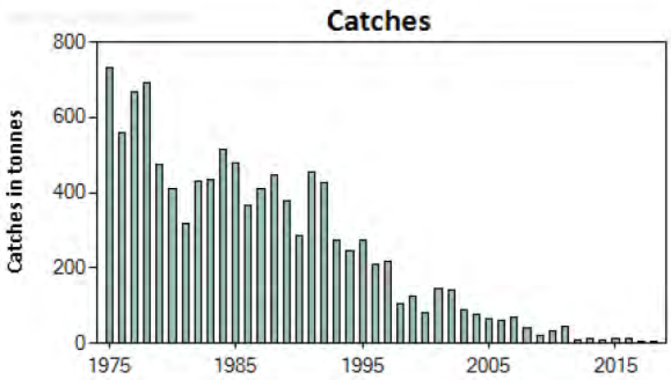

Figure 9.2. FU 25 *Nephrops*. Catches 1975–2018.

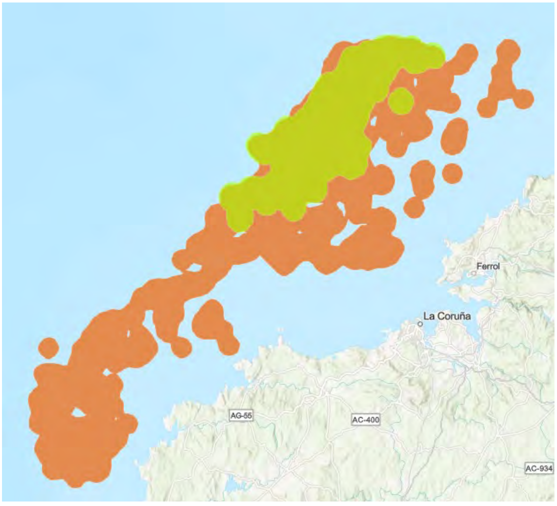

Figure 9.3. FU 25 *Nephrops*. Contraction of the stock area. Brown area: From positions of hauls with *Nephrops* catch since 1983 (3931 km²). Green area: From positions of hauls with *Nephrops* catch since 2017 (1139 km²).

A decrease in FU 25 *Nephrops* recruitment trend since 1985 to 2008 has been observed in the Spanish scientific bottom trawl survey SP-NSGFS (Figure 9.4).

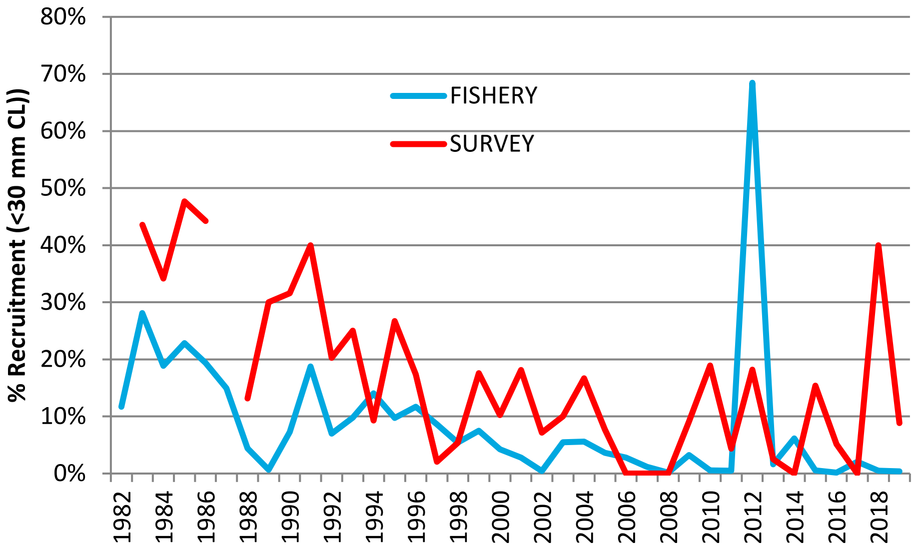

Figure 9.4. FU 25 *Nephrops*. Recruitment proxy. The survey is SP-NSGFS.

ICES advice for this stock has been reducing catch to zero since 2002 (ICES, 2019). The present status of the stock is undesirable (ICES, 2016) and it is considered a stock with an extremely low biomass (ICES, 2017). In 2017, there was established a TAC (total allowable catch) zero for *Nephrops* in Division 8c for the triennium 2017–2019 (EU, 2017) and again in 2019 for the period 2020 to 2022 (EU, 2019). There is a *Nephrops* Sentinel fishery in August and September since 2017.

In the first part of the 2000 decade, the assessment of the stock was analytical using the age-based model XSA (ICES, 2002). Later, in view of the very low levels of landings, the assessment was based in the analysis of the trends of catch and catch per unit of effort (CPUE) series (ICES, 2007).

The necessity of establishing reference points of the stock in relation with the maximum sustainable yield (MSY) has encouraged the use of new assessment methods for data-limited stocks (DLS) as FU 25 *Nephrops* (ICES, 2020b). In that sense ICES planned a workshop about SPiCT in February 2021 (WKMSYSPiCT) with two previous preparatory meetings in 2020.

Stochastic Surplus Production model In Continuous Time (SPiCT) separates random variability of stock dynamics from error in observed indices of biomass and also models the dynamics of the fisheries. This enables error in the catch process to be reflected in the uncertainty of estimated model parameters and management quantities.

Among data-limited methods (DLM), SPiCT could be a suitable tool for the analysis of FU 25 *Nephrops* stock since the stock meets the model assumptions and the model takes into account the long history of the fishery.

9.2 Input data for stock assessment (ToR 1 & 2)

Catch

Nephrops catch data were collected by the Spanish Institute of Oceanography since 1975 by month. Data were provided by ports authorities (sales notes) and crossed with the information provided by scientific personnel in the ports of landing. Since 2003, also logbook information was added. Following the instructions of the preparatory WKMSYSPiCT meeting that was held in November online, focused on the input data evaluation, the estimation of the catches was reviewed which results in:

A modification of the catch time-series adding some *Nephrops* catches from trips that had an incorrect gear identification (red figures in Table 9.1, Figure 9.5).

Table 9.1. FU 25 *Nephrops* previous and new catches series (t) (1975–2019).

Males + Females	Previous FU 25 catches (t)	New FU 25 catches (t)
1975	731	743
1976	559	578
1977	667	828
1978	690	706
1979	475	475
1980	412	532
1981	318	318
1982	431	431
1983	433	433
1984	515	515
1985	477	477
1986	364	398
1987	412	412
1988	445	445
1989	376	405
1990	285	335
1991	453	453
1992	428	428
1993	274	274
1994	245	246
1995	273	275
1996	209	209
1997	219	219
1998	103	103
1999	124	124
2000	81	81
2001	147	147

Males + Females	Previous FU 25 catches (t)	New FU 25 catches (t)
2002	143	143
2003	89	89
2004	75	75
2005	63	63
2006	62	62
2007	67	67
2008	39	39
2009	23	23
2010	32	34
2011	46	46
2012	9	13
2013	11	11
2014	10	10
2015	14	14
2016	13	13
2017	2	7
2018	2	4
2019	3	13

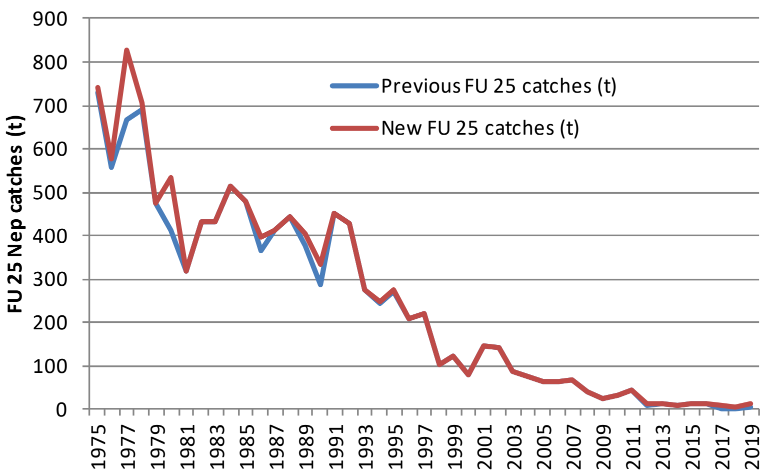

Figure 9.5. FU 25 *Nephrops* previous and new catches series (t) 1975–2019.

As in the period 2017–2019 there was a *Nephrops* TAC of cero tons in Division 8c with a special quota for the FU 25 *Nephrops* sentinel fishery of 2 t by year, the annual catch in this period was estimated (green figures in Table 9.1, Figure 9.5), following the catch trend of the adjacent FU 26 of West Galicia which has a parallel evolution and a similar state to FU 25 along the whole time-series.

These modifications did not imply big changes in the catch time-series (Figure 9.5).

Abundance index

During the SPiCT learning sessions held in October online, it was recommended to use for the FU 25 SPiCT model the *Nephrops* index from bottom trawl scientific survey (SP-NSGFS) (Table 9.2, "Original"; Figure 9.6, red line).

Table 9.2. FU 25 SP-NSGFS survey *Nephrops* index (gramme/haul) (1983–2019). Original and recalculated. There was not survey in 1987. Smaller vessel and smaller gear in 1989. New vessel since 2013.

Males + Females	Original	Recalculated
1983	127	127
1984	574	565
1985	266	281
1986	339	353
1987	There was not survey	
1988	399	453
1989	66	81
1990	215	249
1991	1275	1267
1992	471	468
1993	247	256
1994	154	153
1995	496	494
1996	300	288
1997	58	59
1998	69	74
1999	82	87
2000	55	57
2001	87	90
2002	78	81

Males + Females	Original	Recalculated
2003	25	29
2004	41	57
2005	36	48
2006	9	11
2007	11	10
2008	12	13
2009	25	28
2010	47	45
2011	30	59
2012	30	37
2013	67	96
2014	55	80
2015	20	36
2016	52	81
2017	32	47
2018	35	37
2019	51	49

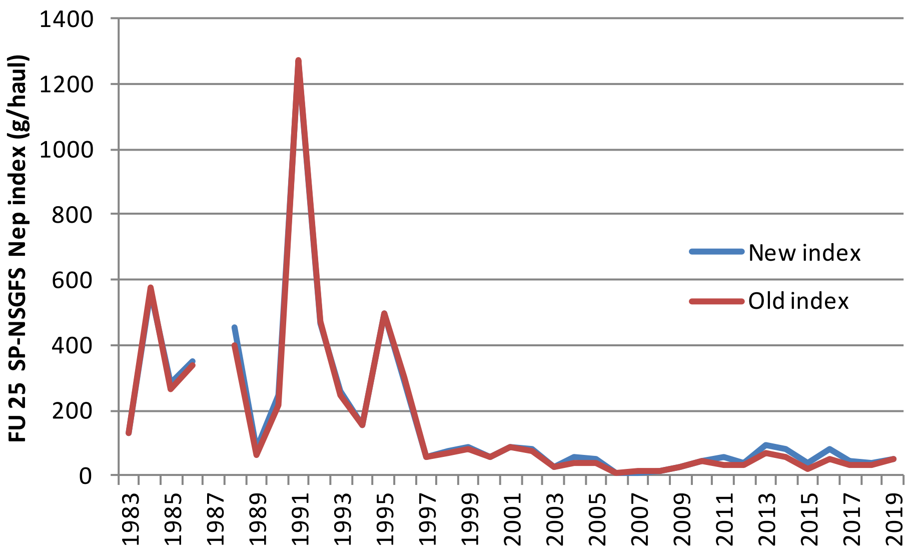

Figure 9.6. FU 25 SP-NSGFS survey *Nephrops* index (gramme/haul) 1983–2019. All hauls (Old index) and only with hauls inside *Nephrops* area (New index). There was not survey in 1987. Smaller vessel and smaller gear in 1989. New vessel since 2013.

In the Data Evaluation meeting which was focused in the input data evaluation, some issues about the quality of the index were raised, specially related with the existence of two marked and very different periods in the index series, till 1996 and from 1997 (Table 9.2, "Original"; Figure 9.6, red line). Therefore, the calculation of the SP-NSGFS index was reviewed.

The original index was calculated with all the hauls carried out in the rectangles of FU 25 (Figure 9.7, middle, blue points).

For the February 2021 WKMSYSPiCT, the *Nephrops* area in the FU 25 was estimated with the position of the hauls with *Nephrops* catch from 1983–2020 trawl survey (SP-NSGFS), 1994–2020 Discard programme and 2017–2020 *Nephrops* Sentinels fisheries (Figure 9.7, green area).

Then, the SP-NSGFS index was recalculated excluding the hauls out of this area (Figure 9.7, right, white points). This did not change the index trend, only increases very slightly the values (Table 9.2, "recalculated"; Figure 9.6, blue line).

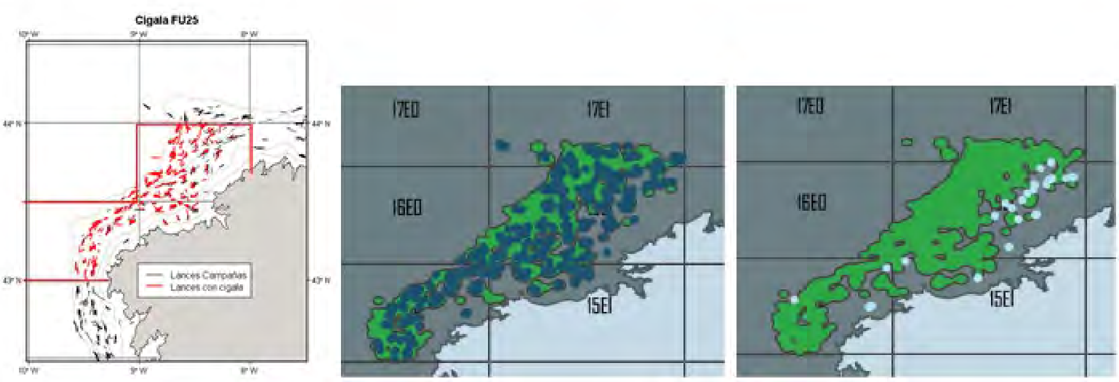

Figure 9.7. FU 25. *Nephrops* area in green. 1983–2019 SP-NSGFS survey hauls positions: left: red: hauls with *Nephrops* catch, black: hauls without *Nephrops* catch); middle: all hauls (blue points); right: hauls out of the *Nephrops* area (white points).

Also, the 1991 value (Table 9.2, Figure 9.6) was checked in the raw data and it was right, corresponds to hauls with very high *Nephrops* catch.

Regarding if the change in 1997 comes from a change of the survey design, in 1997 the survey first depth stratum changed from 30–100 m to 70–120 and the second from 100–200 m to 120–200 m. This could not affect to the index because in the whole survey time-series there was no *Nephrops* at depths lower than 78 m and the stratum and depth are not taken into account in the *Nephrops* index estimation. *Nephrops* index is the average of the yields in gram by haul of the hauls within the *Nephrops* area.

Respect to the cause of the 1997 change could be related to a change of gear, however, the gear, the vessel and the duration of the hauls (30 minutes) have been the same since 1983 to 2012, with the exception of the year 1989, when a smaller vessel and smaller gear were used. After several calibrations, since 2013 a new vessel and gear are used. The gear was similar and there was no change relative to the *Nephrops* catch levels.

Regarding the number and distribution of the hauls along the survey period, they have been similar (Figure 9.8 and Figures 12.1.6a, b, c and d of 2020 ICES WGBIE report).

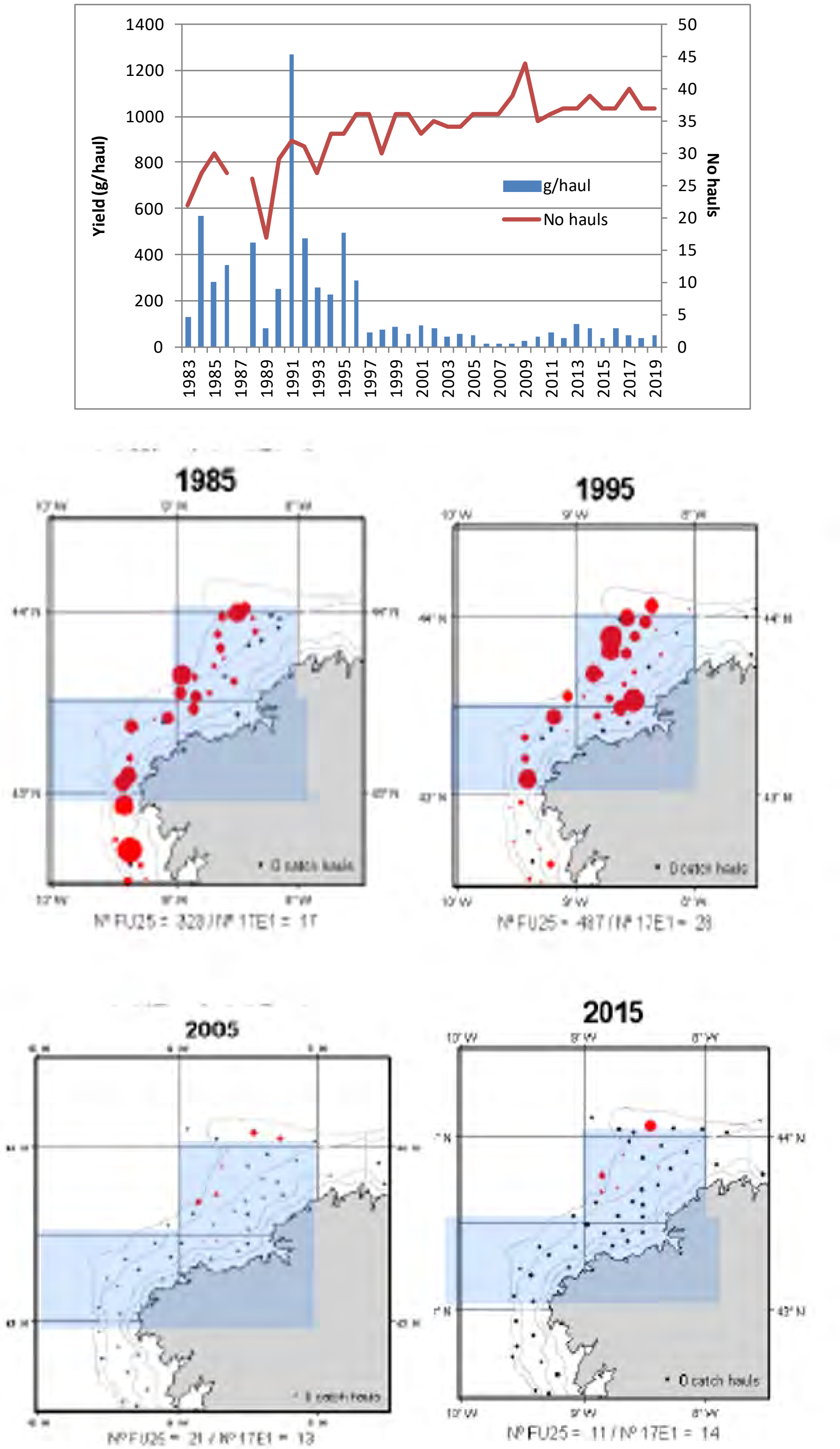

Figure 9.8. FU 25 SP-NSGFS Survey *Nephrops* index (gramme/haul) 1983–2019. Upper panel: No of hauls within the *Nephrops* area along the time-series. There was no survey in 1987. In 1989, a smaller vessel and smaller gear were used. New vessel since 2013. Lower panel (block of 4 plots): Example of survey distribution of hauls in four years.

Respects to the time of the day of the hauls, the hauls in this survey have always been carried out during the daytime, never at nighttime.

A high decrease in middle nineties have been seen also in the *Nephrops* landings of 8c and 9a divisions (both divisions together and separately), in the FU 25 and FU 31 landings and in the percentage of males of FU 31.

Survey and fishery *Nephrops* mean sizes

Frequently the mean size of the individuals collected in a scientific survey is smaller than the mean size from the commercial fleet in the same area. In that cases trends observed in the scientific survey data could be reflected in the commercial catch one or two years later. The comparison of the survey and commercial mean sizes series of the FU 25 (Figure 9.9) shows that in this case, it is not necessary to introduce survey time-series with one year more than the real, since original series trends match (Figure 9.9).

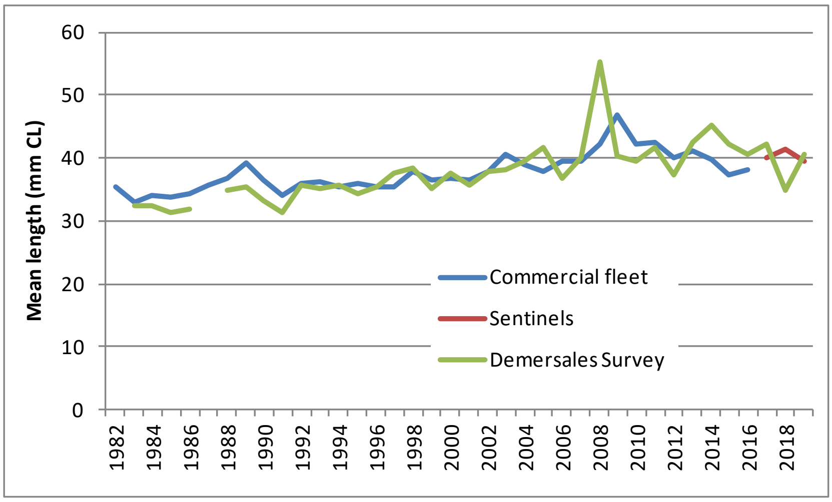

Figure 9.9. FU 25 *Nephrops* mean size (carapace length in mm) from the commercial fishery (1982–2016), the Sentinel fishery (2017–2019) and the SP-NSGFS bottom trawl survey (1983–2019).

9.3 Stock assessment (ToR 3)

9.3.1 Exploratory assessments

In the October Learning sessions, three runs were presented using as index (1) the SP-NSGFS survey *Nephrops* yield, (2) the CPUE and SP-NSGFS survey yield and (3) the CPUE and SP-NSGFS survey yield with the code inp$msytype<-“d”. Annual data were used. The run with SP-NSGFS survey yield as index (1) did not converge and the B_{2019}/B_{MSY} obtained was 0.1 and the F_{2019}/F_{MSY} 0.6. In the runs with CPUE (2 and 3) no stochastic MSY and F_{MSY} were obtained. That is the reason why in run (3) deterministic B_{MSY}, F_{MSY} and MSY were used (inp$msytype<-“d”). In the Learning sessions survey yield was selected as unique index to use in the FU 25 model. Run (1) is call **Run “a”** in the Table 9.3. Only runs with survey yield as unique index are presented in the Table 9.3.

In the November Data evaluation meeting four runs with different catch periods and time units and with males and both sexes data were done (runs b-e in Table 9.3). The four runs converge and have normality problems (in run c-e normality in Table 9.3 should be N instead of Y).

Run b was as the run a but:

- the index 1991 outlier was no substituted by the average of 1990 and 1992;
- the index was scaled for better numerical stability;
- *mstd<-function(x) x/mean(x,na.rm=TRUE);*
- *data$DEM = mstd(data$DEM);*
- a prior assuming by mistake that there was no *Nephrops* explotation before the beginning of the time-series (1975) was used (inp$priors$logbkfrac=c(0,1,1));
- the prior inp$priors$logn=c(log(2),0.5,1) was used to get convergence.

In run b, the assumption of normality did not meet, the B_{2019}/B_{MSY} was 0.1 and F_{2019}/F_{MSY} 0.7

Run c was as the run b but:

- quarterly data were used since *Nephrops* fishery in FU 25 is seasonal with the higher CPUEs in June, July and August;
- only male data were used. Males are more accessible for the fishing gear since ovigerous females stay eight months within the burrow during the egg incubation.

Run c was rejected since:

- the non-annual data cause noise in the analysis and increment the difficulty in get acceptable runs;
- *Nephrops* total allowable catch (TAC) in this area is by ICES division (unique TAC for the whole 8c division. There are two *Nephrops* functional units in 8c (FU 25 and 31). If we would make the analysis by sex, it would have to do four models for the division (FU 25 males, FU 25 females, FU 31 males and FU 31 females), which would increment the difficult of the analysis.

Run d was as run c but:

- Monthly data were use since *Nephrops* fishery in FU 25 is seasonal (Table 9.3).

Run d was rejected by the same reasons than in run c.

Run e was as run d but:

- Only 1997–2019 data were used since there are two periods in the catch and index time-series, until 1996 (with high values) and since 1997 (with low values).

Run e was rejected by the same reasons than in run c and d and also:

- That taking only the last 22 years ignores the oldest levels of reference of the stock, which was one of the advantages of the SPiCT model use.

Along the February meeting thirteen runs were presented. All of them with inp$dteuler=1/12.

Run 0 was the initial run proposed to the WK. Run 0 was as run e but:

- with the whole time-series, 1975–2019 catches and 1983–2019 index;
- with annual data;
- the index was recalculated only taking into account hauls within *Nephrops* area;
- index 1991 outlier was deleted;
- a medium level of *Nephrops* exploitation before the beginning of the time-series (1975) was assumed (inp$priors$logbkfrac=c(log(0.5),1,1));

- new priors were introduced in order to solve normality problems and decreased the confidence intervals of the results

  > inp$priors$logalpha <- c(0,0,0)

  > inp$priors$logbeta <- c(0,0,0)

  > inp$priors$logsdf <- c(log(3), 0.5, 1)

  > inp$priors$logsdc <- c(log(0.1), 0.2, 1)

  > inp$stdevfacI <- list(c(rep(2, 12), rep(1, length(inp$timeI[[1]]) - 12)))

B_{2019}/B_{MSY} in run 0 was 0.2 and F_{2019}/F_{MSY} 0.5

The following runs were with the changes proposed by the WK experts.

Run 1 was as run 0 but:

- with inp$priors$logbkfrac=c(log(0.5),**0.2**,1);
- without inp$priors$logn=c(log(2),0.5,1);
- with inp$priors$logr <- c(log(0.2), 0.2,1) (Table 9.3).

The catch forecast was calculated with the old version of the code and has no intermediated year. B_{2019}/B_{MSY} in run 1 was 0.13 and F_{2019}/F_{MSY} 0.44.

Run 2 was as run 1 but:

- with inp$priors$logn=c(log(2),0.5,1).

B_{2019}/B_{MSY} in run 2 was 0.13 and F_{2019}/F_{MSY} 0.43.

Run 1b was as run 1 but:

- using the recorded catches for 2017–2019 (2 t, 2 t and 3 t respectively) instead of the estimated catches (7 t, 4 t and 13 t respectively).

The catch forecast was calculated with the old version of the code and has no intermediated year. There were normality problems. B_{2019}/B_{MSY} in run 1b was 0.12 and F_{2019}/F_{MSY} 0.10.

Run 1c was as run 1b but:

- with inp$priors$logsdf=c(1,0.5,1);
- without inp$stdevfacI <- list(c(rep(2, 12), rep(1, length(inp$timeI[[1]]) - 12)));
- with inp$stdevfacC=c(rep(1,42),6,6,6).

The following runs are sensitivity runs based in Run 1c.

Run 1d was as run 1c but:

- with inp$priors$logbkfrac=c(log(0.3),0.2,1) that is high *Nephrops* exploitation before 1975.

Run 1e was as run 1c but:

- with inp$priors$logbkfrac=c(log(0.8),0.2,1) that is low *Nephrops* exploitation before 1975

Run 1f was as run 1c but:

- with inp$priors$logsdc=c(log(**0.2**),0.2,1).

Run 1g was as run 1c but:

- with inp$priors$logsdc=c(log(**0.3**),0.2,1).

Run 1d2 was as run 1d, **Run 1e2** as run 1e, **Run 1f2** as run 1f, **Run 1g2** as run 1g but:

- with inp$phases$logn=-1.

Diagnostics and estimates of the runs 1d2–1g2 are in Table 9.4.

Table 9.3. Characteristics of the FU 25 SPiCT runs carried out with SP-NSGFS *Nephrops* yield as index.

		Catch				Index				Priors											
Meeting	Run	Catch period	Catch time unit	2017-2019 catches	Sex	Index Hauls from FU	Index 1991 outlier	Index scaled	Index lag	Previous Stock explotaition (BK frac)	logn	logalpha	logbeta	logsdf	logsdc	stdevfacI list(c(rep(2, 12), rep(1, length(inp$timeI[[1]]) - 12)))	log r	stdevfacC	Convergence	Normality	Comment
Oct 20	a	1975-2019	Ye	E	B	Rc	A	N	N	-	-	-	-	-	-	-	-		**N**	-	-
Nov 20	b	1975-2019	Ye	E	B	Rc	**NS**	**Y**	N	c(0,1,1)	c(log(2),0.5,1)	-	-	-	-	-	-		Y	**N**	-
Nov 20	c	1975-2019	**Q**	E	**M**	Rc	NS	Y	N	c(0,1,1)	c(log(2),0.5,1)	-	-	-	-	-	-		Y	Y	**TAC for 2 FUs**
Nov 20	d	1975-2019	**Mo**	E	M	Rc	NS	Y	N	c(0,1,1)	c(log(2),0.5,1)	-	-	-	-	-	-		Y	Y	**TAC for 2 FUs**
Nov 20	e	**1997-2019**	Mo	E	M	Rc	NS	Y	N	c(0,1,1)	c(log(2),0.5,1)	-	-	-	-	-	-		Y	Y	**Ignores oldest level of reference**
Feb 21	0	1975-2019	Y	E	B	**NeA**	**D**	Y	N	**c(log(0.5),1,1)**	c(log(2),0.5,1)	**c(0,0,0)**	**c(0,0,0)**	**c(log(3),0.5,1)**	**c(log(0.1),0.2,1)**	**Y**	-		Y	Y	
Feb 21	1	1975-2019	Y	E	B	NeA	D	Y	N	**c(log(0.5),0.2,1)**	-	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	**c(log(0.2),0.2,1)**		Y	Y	
Feb 21	2	1975-2019	Y	E	B	NeA	D	Y	N	c(log(0.5),0.2,1)	**c(log(2),0.5,1)**	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	c(log(0.2),0.2,1)		Y	Y	
Feb 21	1b	1975-2019	Y	**R**	B	NeA	D	Y	N	c(log(0.5),0.2,1)	-	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	c(log(0.2),0.2,1)	-	Y	N	Wrong years in catch forecast
Feb 21	1c	1975-2019	Y	R	B	NeA	D	Y	N	c(log(0.5),0.2,1)	-	c(0,0,0)	c(0,0,0)	**c(1,0.5,1)**	c(log(0.1),0.2,1)	-	c(log(0.2),0.2,1)	**c(rep(1,42),6,6,6)**	Y	Y	
Feb 21	1d	1975-2019	Y	R	B	NeA	D	Y	N	**c(log(0.3),0.2,1)**	-	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	c(log(0.1),0.2,1)	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	Sensitivity run
Feb 21	1e	1975-2019	Y	R	B	NeA	D	Y	N	**c(log(0.8),0.2,1)**	-	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	c(log(0.1),0.2,1)	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	Sensitivity run
Feb 21	1f	1975-2019	Y	R	B	NeA	D	Y	N	c(log(0.5),0.2,1)	-	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	**c(log(0.2),0.2,1)**	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	Sensitivity run
Feb 21	1g	1975-2019	Y	R	B	NeA	D	Y	N	c(log(0.5),0.2,1)	-	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	**c(log(0.3),0.2,1)**	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	Sensitivity run
Feb 21	1d2	1975-2019	Y	R	B	NeA	D	Y	N	**c(log(0.3),0.2,1)**	**inp$phases$logn=-1**	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	c(log(0.1),0.2,1)	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	N	Sensitivity run
Feb 21	1e2	1975-2019	Y	R	B	NeA	D	Y	N	**c(log(0.8),0.2,1)**	inp$phases$logn=-1	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	c(log(0.1),0.2,1)	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	N	Sensitivity run
Feb 21	1f2	1975-2019	Y	R	B	NeA	D	Y	N	c(log(0.5),0.2,1)	inp$phases$logn=-1	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	**c(log(0.2),0.2,1)**	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	**FINAL RUN**
Feb 21	1g2	1975-2019	Y	R	B	NeA	D	Y	N	c(log(0.5),0.2,1)	inp$phases$logn=-1	c(0,0,0)	c(0,0,0)	c(1,0.5,1)	**c(log(0.3),0.2,1)**	-	c(log(0.2),0.2,1)	c(rep(1,42),6,6,6)	Y	Y	Sensitivity run

- = Default, A=Average, B=Both, D=Deleted, E=Estimated, M=Males, Mo=Month, NeA=Nephrops area, NS=Not substituted, Q=Quarter, R=Real, Rc=Rectangles, Ye=Year

All runs with SP-NSGFS survey Nephrops yield as index

Table 9.4. Diagnostics & estimates of FU 25 runs 1d2 to 1g2.

Run	All finite	bmsyk	magnitude B/Bmsy, F/Fmsy	sensitivity to initial values	corr values > 0.55	Shapiro Catch	Shapiro Survey	rho B/Bmsy	rho F/Fmsy	n	r	B2019/Bmsy	b/tr	b/blim	F2019/Fmsy
1d2	Y	0.5	(1,1)	ok	0.89: logK~logm	0.038	0.367	-0.139	0.116	fixed=2	0.184	0.07	0.15	0.25	0.10
1e2	Y	0.5	(1,1)	ok	0.85: logK~logm	0.039	0.334	-0.193	0.143	fixed=2	0.188	0.16	0.32	0.53	0.10
1f2	**Y**	**0.5**	**(1,2)**	**ok**	**none**	**0.251**	**0.299**	**0.244**	**-0.111**	**fixed=2**	**0.174**	**0.11**	**0.22**	**0.36**	**0.22**
1g2	Y	0.5	(1,2)	ok	none	0.339	0.333	0.243	-0.135	fixed=2	0.175	0.11	0.21	0.35	0.30

Catch: 1975-2019 (real catch data 2017-2019); survey: 1983-2019 (scaled to 1) (dteuler=1/12)

1f2 = FINAL RUN

9.3.2 Final assessment

WKMSYSPiCT accepted the SPiCT run ‘1f2’ (Table 9.3) for the assessment of FU 25. Run ‘1f2’ uses the whole catch time-series (1975–2019), the whole SP-NSGFS survey index time-series (1983–2019) with annual and both sexes data and the recorded catches for 2017–2019. The index was calculated only with the hauls of the survey within the *Nephrops* area, the index 1991 outlier was deleted and the index was scaled. No lag in the index time-series respect to the catch time-series was introduced. A medium *Nephrops* level of exploitation before 1975 was assumed and several priors were used to obtain convergence, solve normality problems and decreased the intervals of confidence of the results (Table 9.3). Fit, priors, diagnostic and retrospective pattern are shown in Figure 9.11, Figure 9.12, Figure 9.13 and Figures 9.14 and 9.15, respectively. Results of the model are shown in Table 9.5 and Table 9.6. Below is shown the R code used:

```
##Scale survey index to mean 1 (for better numerical stability)
>mstd=function(x) x/mean(x,na.rm=TRUE)
>fu25$DEM = mstd(fu25$DEM)
#Create the inp object for the model
>inp = list(timeC=fu25$TC, obsC=fu25$C,
+                    obsI=list(obsI2=fu25$DEM),
+                    timeI=list(timeI2=fu25$TD+0.8333333))  #survey time set to October
## -- Time step & management period
>inp$dteuler=1/12
>inp$maninterval = c(2021, 2022)   #management starts with one intermediate year (i.e. 2020)
>inp$maneval = 2022
>inp=check.inp(inp)
>inp$dtc
## -- Priors (final run)
> inp$priors$logbkfrac=c(log(0.5),0.2,1)    #medium initial depletion
> inp$priors$logr=c(log(0.2),0.2,1)        #intrinsic biomass growth
> inp$phases$logn= -1                    #n=2 (Schaefer production curve)
> inp$priors$logalpha=c(0,0,0)            # deactivate
> inp$priors$logbeta=c(0,0,0)             # deactivate
> inp$priors$logsdf=c(1, 0.5, 1)       # process noise of F
> inp$priors$logsdc=c(log(0.2), 0.2, 1)     # observation noise Catch
> inp$stdevfacC=c(rep(1,42),6,6,6)       # extra uncertainty in 2017–2019
```

Table 9.5. Results of the model 1f2.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 81.3183593
Euler time step (years):  1/12 or 0.08333
Nobs C: 45,  Nobs I1: 35

Priors
      logn  ~  dnorm[log(2), 2^2]
      logr  ~  dnorm[log(0.2), 0.2^2]
 logbkfrac  ~  dnorm[log(0.5), 0.2^2]
    logsdf  ~  dnorm[log(2.718), 0.5^2]
    logsdc  ~  dnorm[log(0.2), 0.2^2]

Fixed parameters
   fixed.value
 n           2

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha    28.1132155    0.0161374 4.897645e+04  3.3362398
 beta      0.4933163    0.2746009 8.862350e-01 -0.7066048
 r         0.1741026    0.1245565 2.433572e-01 -1.7481105
 rc        0.1741026    0.1245565 2.433572e-01 -1.7481105
 rold      0.1741026    0.1245565 2.433572e-01 -1.7481105
 m       379.9429305  277.5265125 5.201544e+02  5.9400211
 K      8729.1731475 6093.6758391 1.250452e+04  9.0744259
 q         0.0011500    0.0007941 1.665400e-03 -6.7680242
 sdb       0.0231254    0.0000137 3.903151e+01 -3.7668223
 sdf       0.3854288    0.2569935 5.780510e-01 -0.9533989
 sdi       0.6501303    0.5101656 8.284945e-01 -0.4305825
 sdc       0.1901383    0.1401475 2.579609e-01 -1.6600037


Stochastic reference points (Srp)
         estimate        cilow        ciupp   log.est rel.diff.Drp
 Bmsys 4357.2593252 3042.8474094 6239.4547845  8.379599 -0.001681619
 Fmsys    0.0869179    0.0621944    0.1214695 -2.442791 -0.001534769
 MSYs   378.7227628  276.9987403  517.8035500  5.936804 -0.003221796

States w 95% CI (inp$msytype: s)
                  estimate       cilow       ciupp   log.est
 B_2019.92      469.1005174 257.0185479 856.1844939  6.150817
 F_2019.92        0.0193988   0.0043538   0.0864340 -3.942542
 B_2019.92/Bmsy   0.1076595   0.0531516   0.2180663 -2.228782
 F_2019.92/Fmsy   0.2231858   0.0496640   1.0029772 -1.499751
```

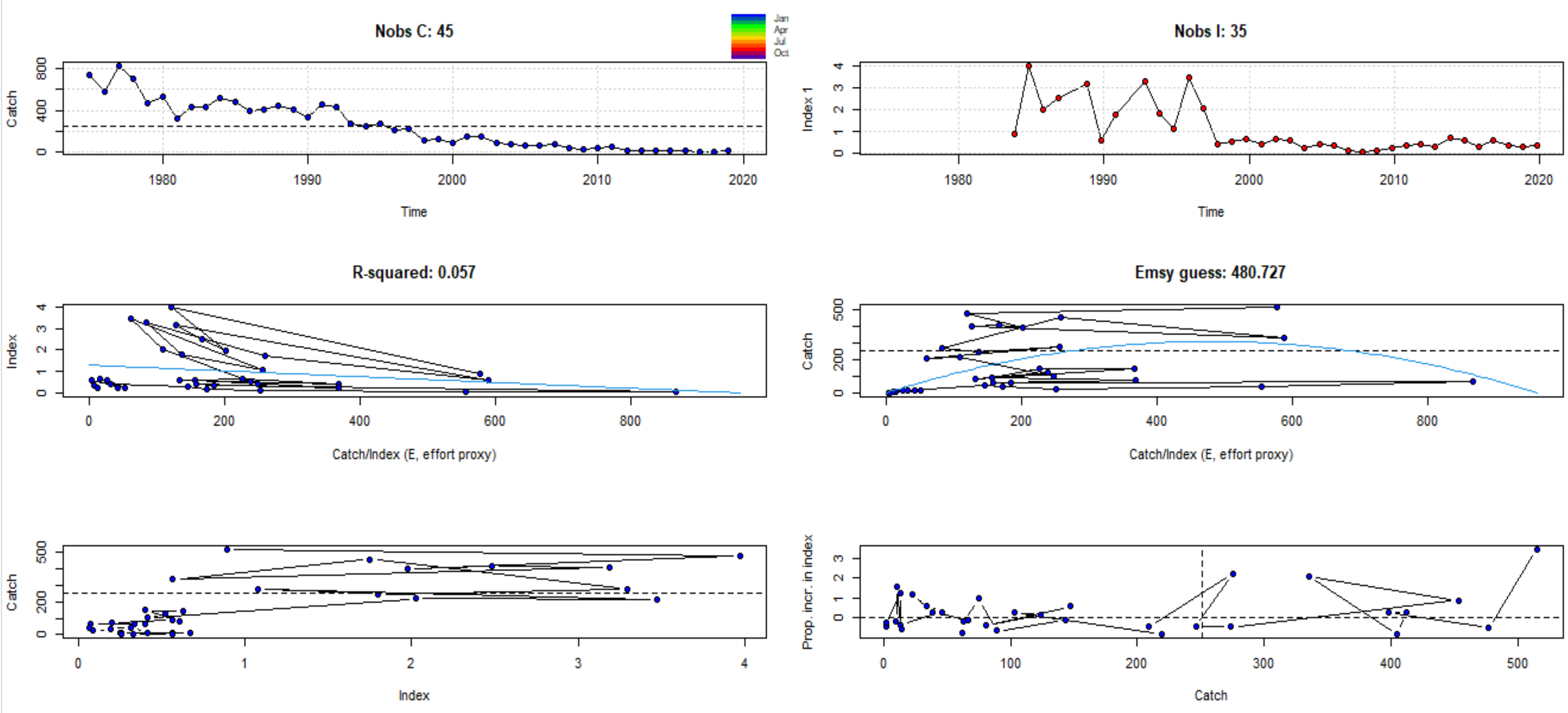

Figure 9.10. Catch and Index time-series, Index vs. Catch/Index, Catch vs Catch/Index, Catch vs Index and Proportional increment in Index vs Catch.

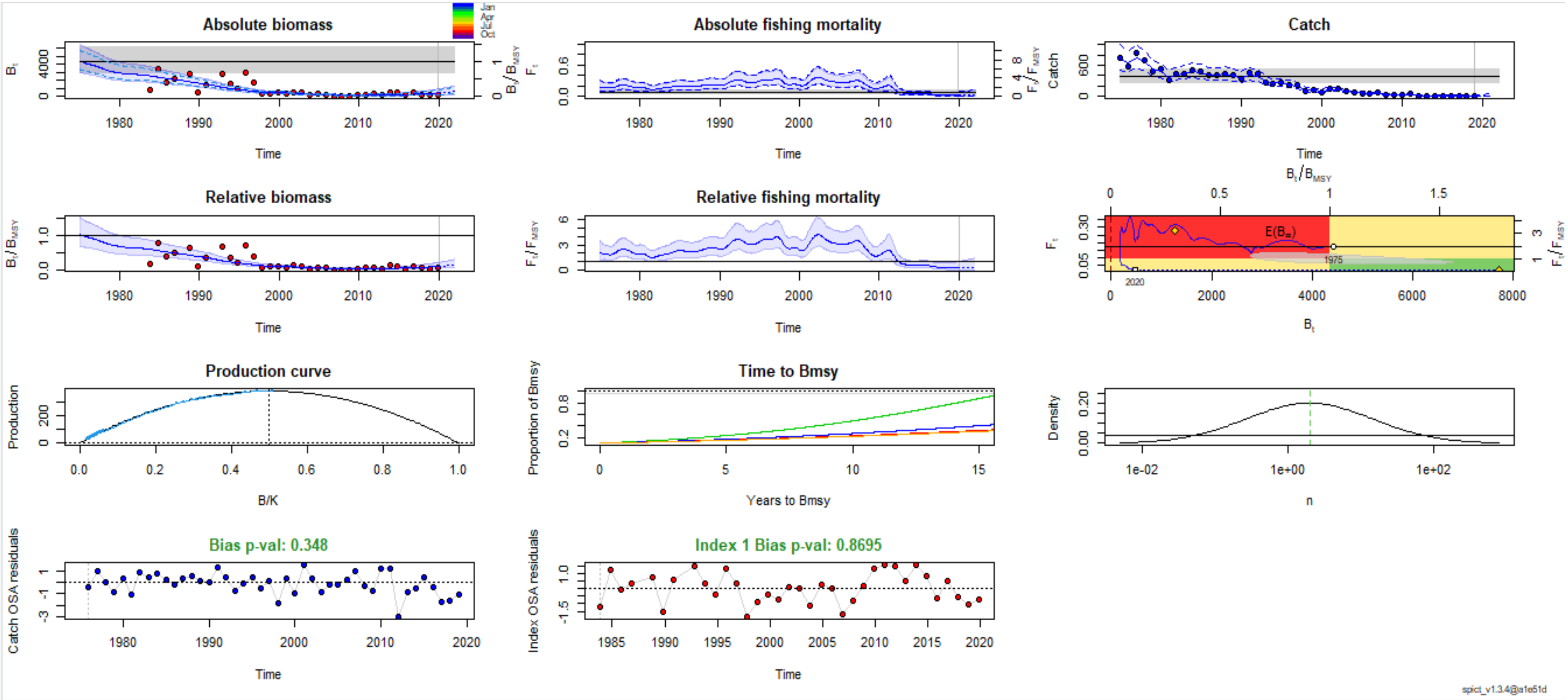

Figure 9.11. Results of the model 1f2 fit.

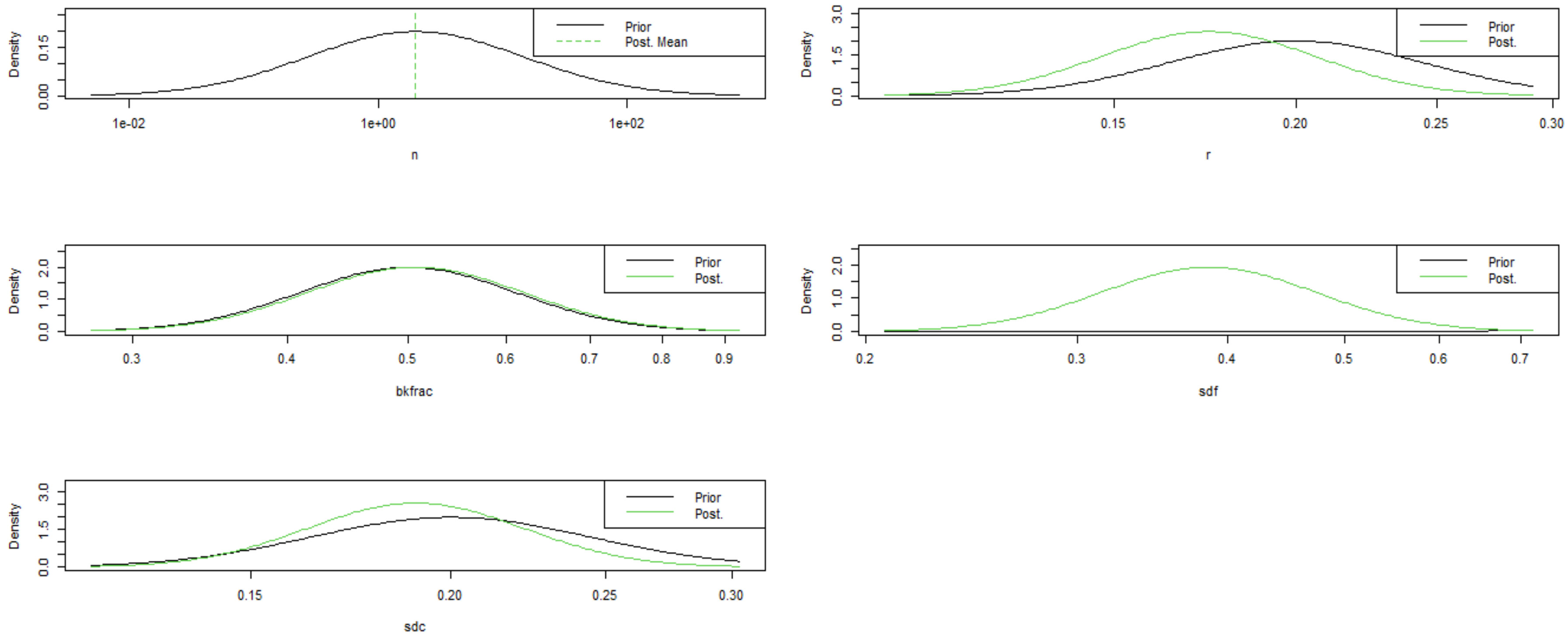

Figure 9.12. Model priors.

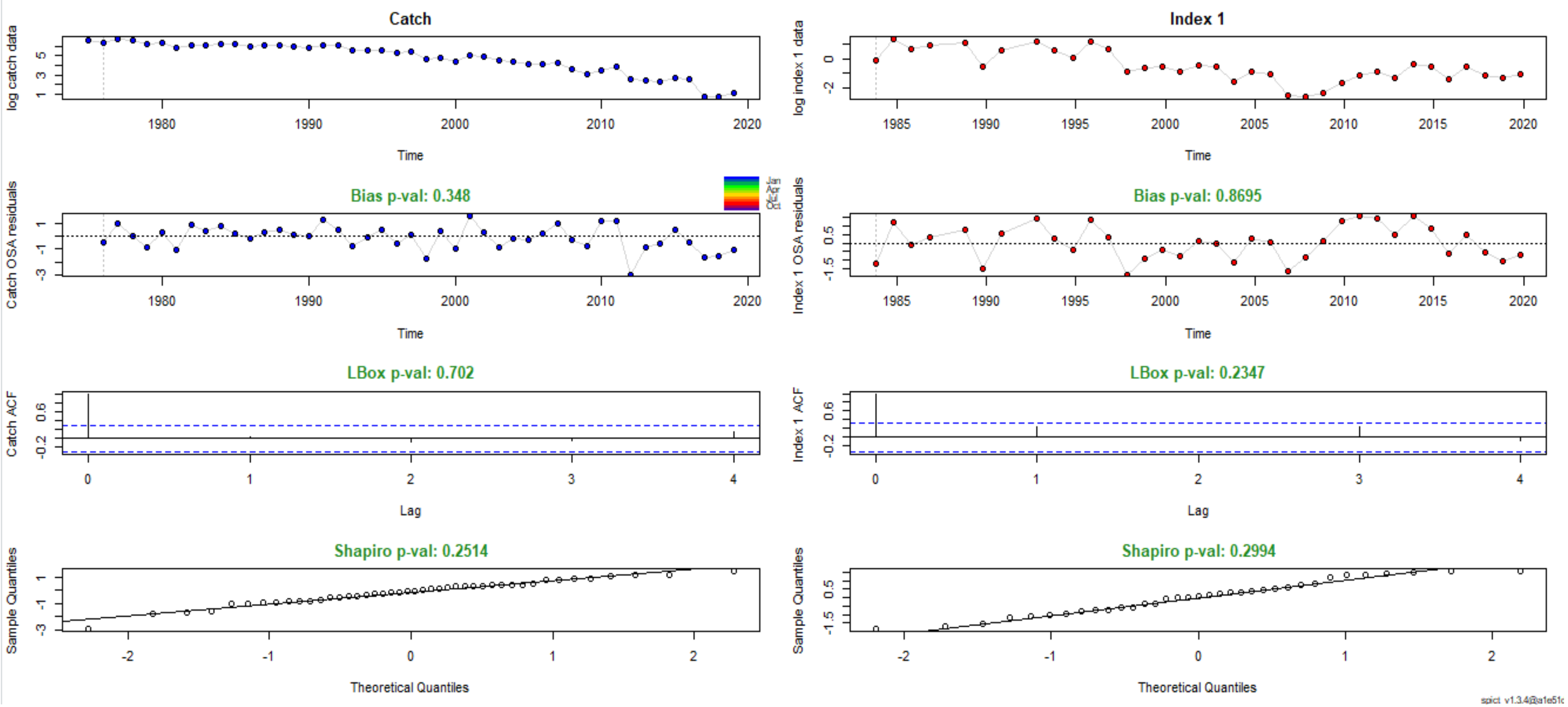

Figure 9.13. Model diagnostic of model 1f2 fit.

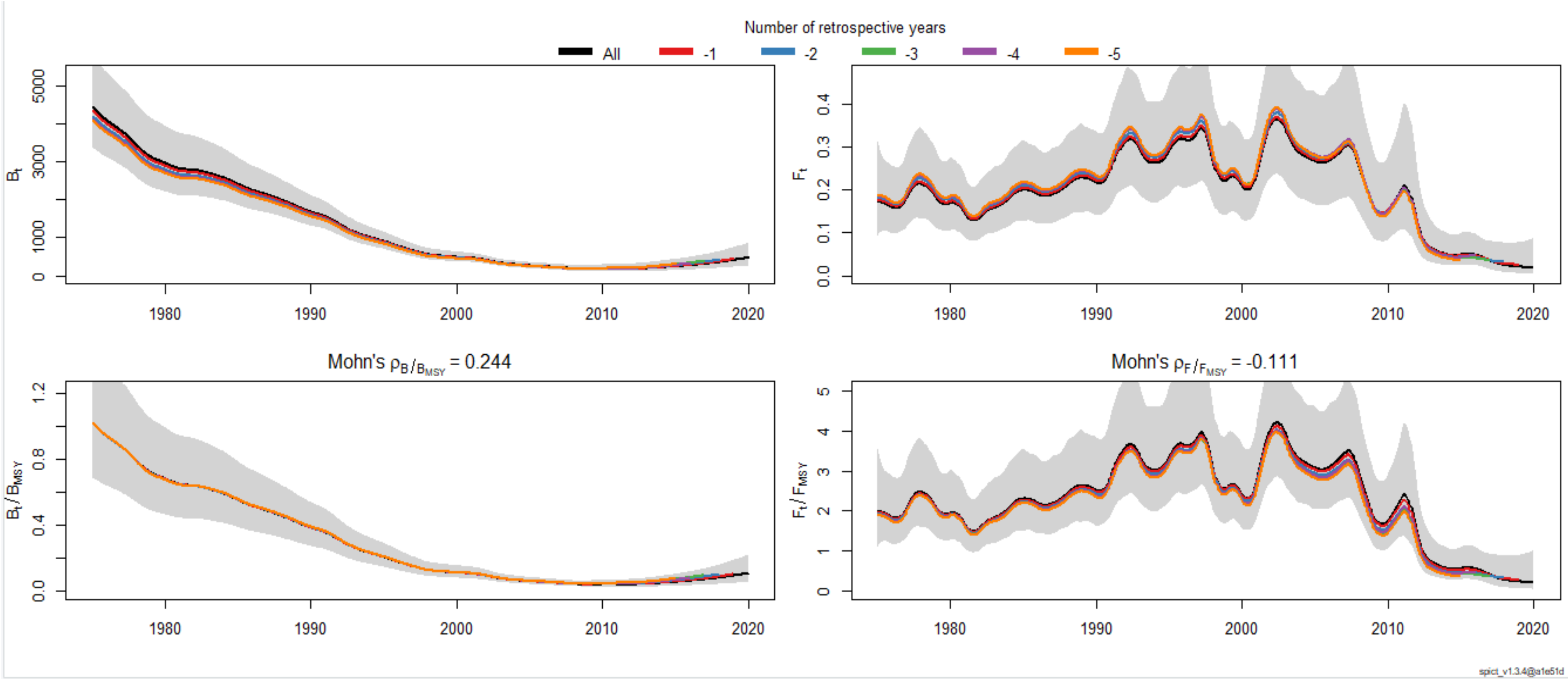

Figure 9.14. B_t, F_t, B_t/B_{MSY} and F_t/F_{MSY} retrospective analysis for model 1f2.

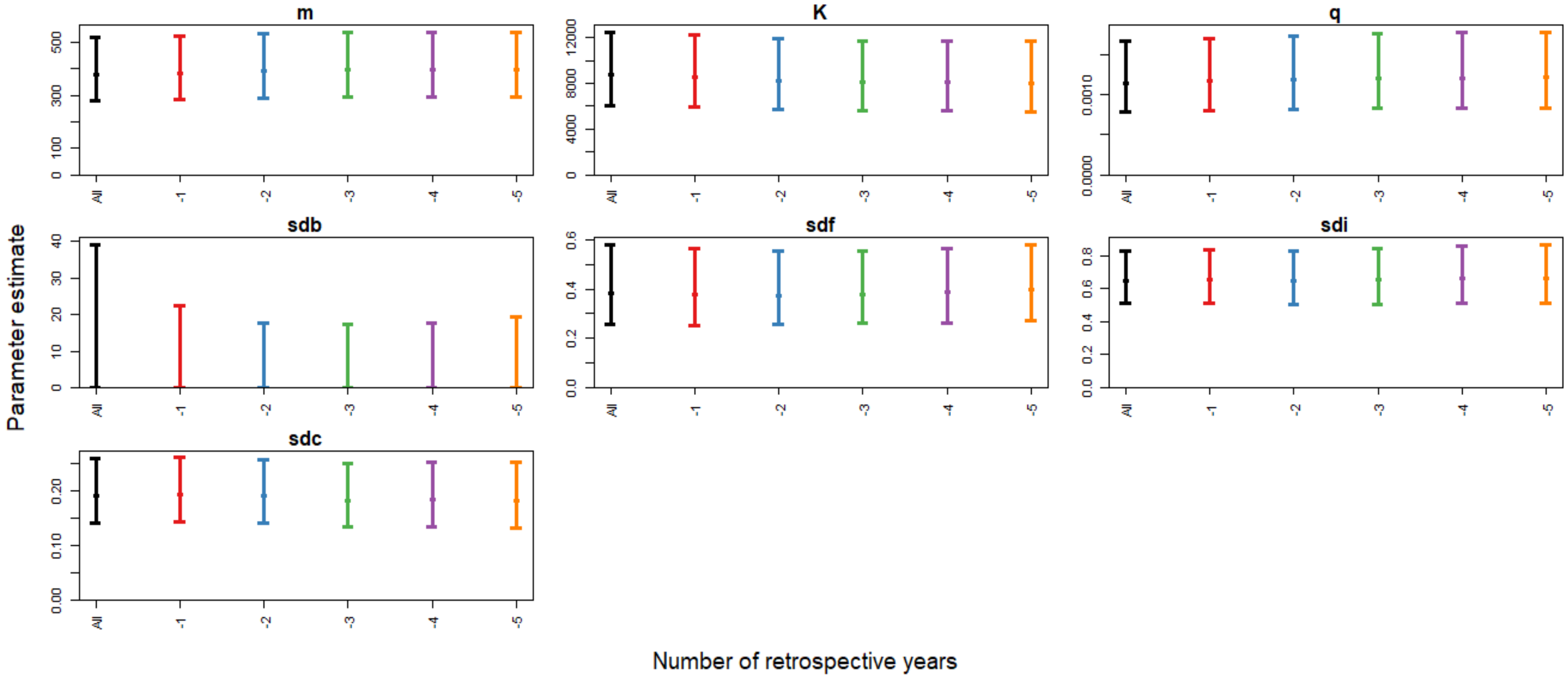

Figure 9.15. Parameter estimate vs number of retrospective years for model 1f2.

Table 9.6. B_{MSY}, $B_{trigger}$, B_{lim}, B_2019/B_{MSY}, B_2019/$B_{trigger}$, B_2019/B_{lim}.

```
> Bmsy; Btrigger; Blim
[1] 4357.259
[1] 2178.63
[1] 1307.178
```

```
> round(B_2019/Bmsy,2);round(B_2019/Btrigger,2); round(B_2019/Blim,2)
[1] 0.04
[1] 0.08
[1] 0.14
```

9.4 Catch forecast (ToR 4)

Catch forecast was carried out using SPiCT version 1.3.4 and R code presented during the WKM-SYSPiCT. Forecast was conducted using an intermediate year. Results for the four different scenarios agreed in the WKMSYSPiCT are show in the Table 9.7. Harvest control rules plots are also presented in Figure 9.16.

Table 9.7. Catch forecast for FU 25 with different management scenarios.

```
SPiCT timeline:

      Observations            Intermediate            Management
    1975.00 - 2020.00       2020.00 - 2021.00      2021.00 - 2022.00
  |----------------------| ----------------------| ----------------------|

Management evaluation: 2022.00

Predicted catch for management period and states at management evaluation tim
e:

                        C B/Bmsy F/Fmsy
1. F=0                0.0   0.15   0.00
2. F=Fsq             11.4   0.15   0.22
3. F=Fmsy             0.0   0.15   0.00
4. F=Fmsy_C_fractile  0.0   0.15   0.00

95% confidence intervals for states:

                     B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. F=0                    0.07      0.31      0.00      0.00
2. F=Fsq                  0.07      0.31      0.03      1.43
3. F=Fmsy                 0.07      0.31      0.00      0.00
4. F=Fmsy_C_fractile      0.07      0.31      0.00      0.00
```

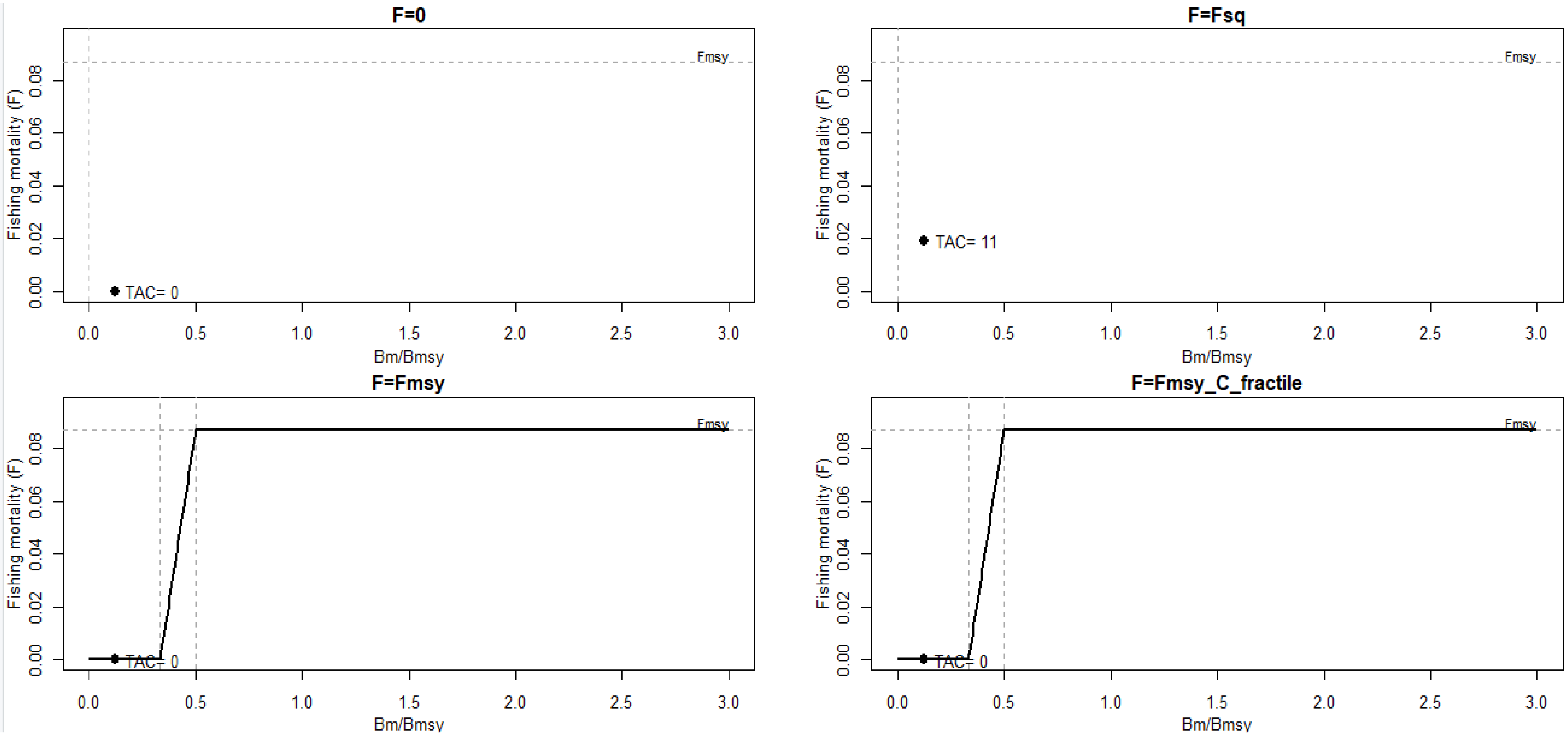

Figure 9.16. Harvest control rules plots for different scenarios for *Nephrops* FU 25. Fishing mortality (F) vs B_m/B_{ms} for the scenarios F=0, $F=F_{sq}$, $F=F_{MSY}$ and $F=F_{MSY}$_C_fractile.

9.5 Future considerations/recommendations

Despite fishing mortality (F) in the last year of the time-series (2019) is below F_{MSY} (22%), 2019 biomass is 11% of the B_{MSY}. The stock has an extremely low biomass, along the time-series the catch has decreased by 98% and the area of the stock by 71%. Therefore, the management of the stock should be established under a precautionary approach.

9.6 Reviewers report

Massimiliano Cardinale, Henning Winker and Casper Berg

The stock assessments of these two Functional Units (FUs) are each based on a relatively long catch time-series and a survey index. Commercial CPUE, even where available, were not used in the assessment as suggested at the data meeting. Further analysis presented at the benchmark meeting corroborated that the declining trend in the survey index is robust with respect to missing data and to the different number of hauls over the time-series for both FUs. In addition, spatial maps of survey catch rates confirm a substantial spatial decline in abundance over time for both FUs, particularly in the first part of the time-series, which is also consistent with the trend in catches over time. The stock area occupied has decreased to about 71% for FU 25 and about 49% for FU 31. Furthermore, the index of recruitment from both the commercial fisheries and the survey show substantial declines after the mid-1990s for both FUs. Therefore, the trend for both catches and survey indices is consistent with a depleted stock for both FUs.

The initial runs showed rather large estimates of uncertainty, together with moderate to unsatisfactory model diagnostics. The models estimate a nearly pristine stock in the start of the time-series. However, catches peaked at the start of the time-series, which most likely implies that the fishery has started long before 1975 and 1983 for FU 25 and 31, respectively. It was therefore suggested to perform an alternative model configuration, constraining the b/k ratio prior to be much lower than 1. This should not have an effect on the trend but could affect the stock status in the terminal year. Accordingly, alternative model runs with lower b/k prior means of 0.5 were evaluated. Although these produced slightly improved model diagnostics, parameter uncertainty still remained relatively large, the runs showed undesirable retrospective patterns, and the stock at the start of the time-series were still estimated to be close to pristine, which does not match the history of the fishery. As a result, alternative runs were requested during the benchmark meeting with a tighter prior on the b/k ratio (logbkratio = c(log(0.5),0.2,1) and on the shape parameter 'n' (i.e. 0.2). The shape parameter 'n' was found to be poorly estimated for both stocks, which resulted in some retrospective patterns. For both stocks, it was therefore advised to fix the shape parameter to 2 (Schaefer model). In addition, both stocks applied a prior on the intrinsic growth rate parameter 'r' with a mean of 0.2 and a CV of 0.2, and also priors on the CV of the catches and on the F diffusion process (replacing the default SPiCT priors). The heavy use of priors for these stocks was necessary to obtain stable assessment results. However, sensitivity runs were made to ensure that the main output (F/F_{MSY} and B/B_{MSY} in the final year) were relatively robust to the choice of priors.

From 2016 to 2017, the agreed TAC was reduced from 48 tonnes to zero for FU 25, and the TAC has remained at zero in the following years (with exception of a sentinel fishery). Concerns were raised about the uncertainty of the very low reported catches from 2017, which are likely to have a higher CV than the years prior to 2017. This issue was addressed by assuming a higher standard deviation for catches in the years 2017–2019 for this stock. This assumption will need to be re-evaluated for future years, particularly if the TAC is increased again.

Conclusions

The results did corroborate those obtained from the previous configurations and thus run 1f2 was agreed as the base case model for providing advice for FU 25. For both stocks, n was fixed to 2 (i.e. Schaefer model to improve the retrospective of B/B_{MSY}). This improves considerably the retrospective and the other diagnostics. For FU 31 run 3 was considered as the final model to be used for providing advice.

9.7 References

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10 Norway lobster (*Nephrops norvegicuss*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay and Cantabrian Sea) (nep.fu.31)

10.1 Introduction

Nephrops Functional Unit (FU) 31 (Cantabrian Sea) extends between 6°W and 2°W along the coast of the North of Spain (ICES Division 8c, Figure 10.1).

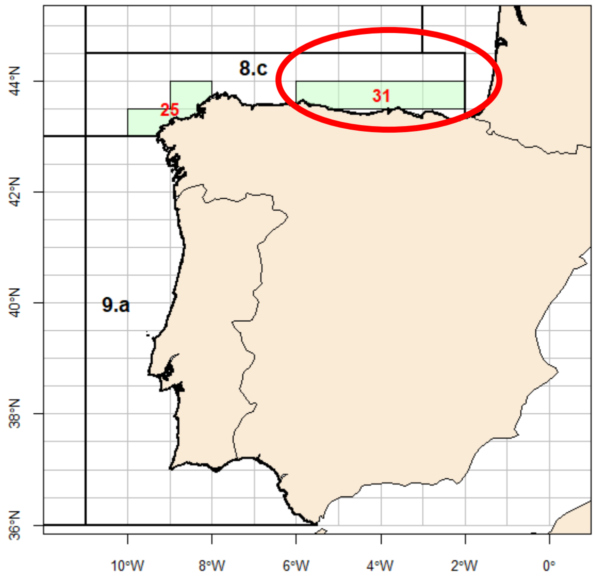

Figure 10.1. *Nephrops* functional units in Division 8.c. FU 31 covers statistical rectangles 16E4–E7.

The species is mostly a bycatch of the bottom trawl fleet that targets hake, megrim and monkfish in the area. The exploitation of the FU 31 stock affects the conservation of the large size individuals, which are the most efficient in terms of reproduction. FU 31 *Nephrops* catch has decreased a 98% between 1989 and 2016 (Figure 10.2) (ICES, 2020) and there has also been a contraction of the stock area of 49% (Figure 10.3).

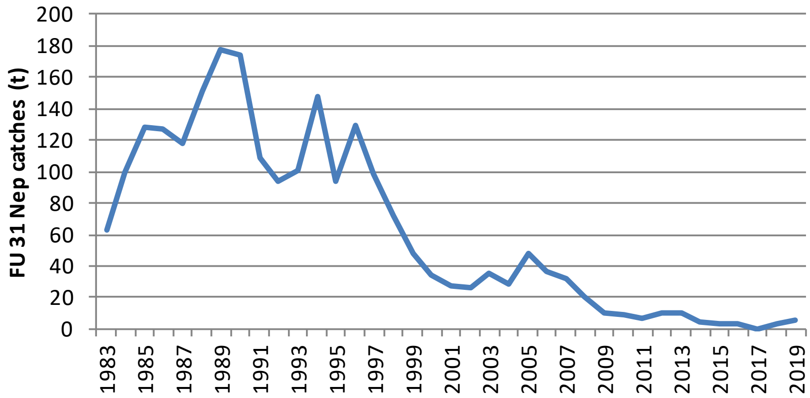

Figure 10.2. FU 31 *Nephrops*. Catches 1983–2019.

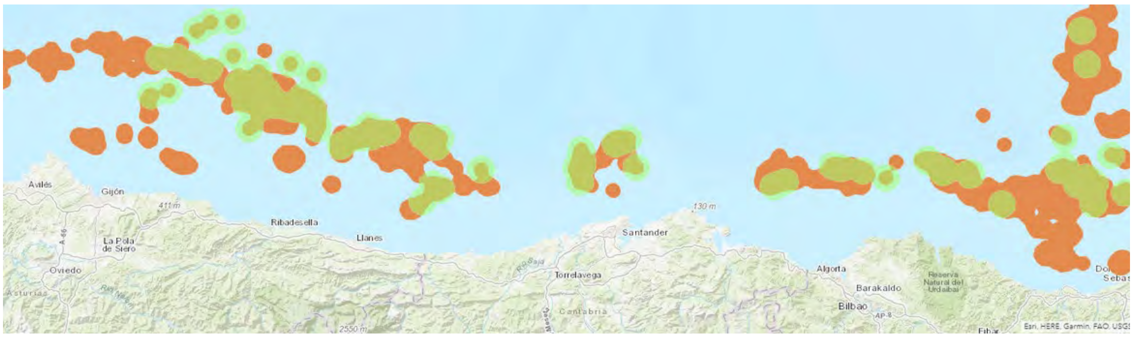

Figure 10.3. FU 31 *Nephrops*. Possible reduction of the stock area. Brown area: Estimated with the positions of the hauls with *Nephrops* catch since 1983 (4714 km²). Green area: Estimated with the positions of the hauls with *Nephrops* catch since 2017 (2545 km²).

A decrease in FU 31 *Nephrops* recruitment trend since 1990 to 2009 has been observed in the Spanish scientific bottom trawl survey SP-NSGFS (Figure 10.4).

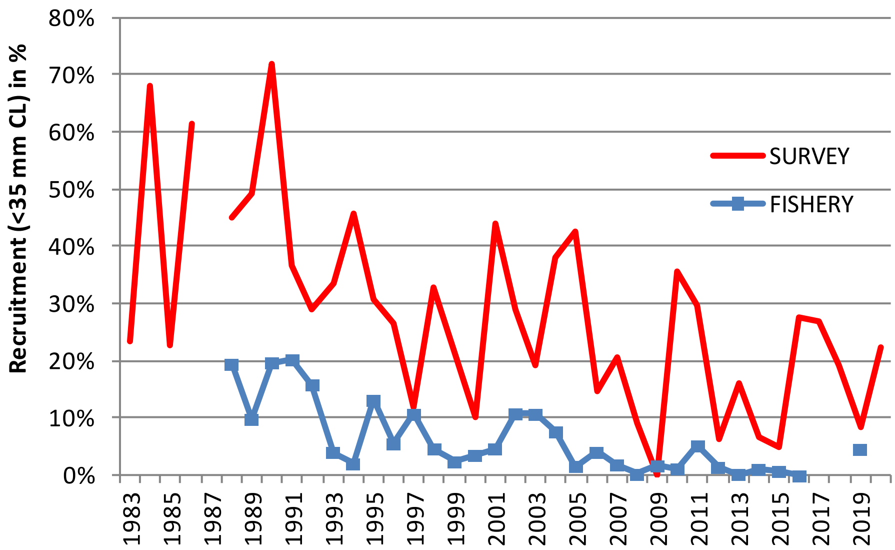

Figure 10.4. FU 31 *Nephrops*. Recruitment proxy. The survey is SP-NSGFS.

ICES advice for this stock has been reducing catch to zero since 2002 (ICES, 2019). The present status of the stock is undesirable (ICES, 2016) and it is considered a stock with an extremely low biomass (ICES, 2017). In 2017 there was established a TAC (total allowable catch) zero for *Nephrops* in division 8c for the triennium 2017–2019 (EU, 2017) and again in 2019 for the period 2020 to 2022 (ICES, 2019). There is a *Nephrops* Sentinel fishery in July since 2019.

In the first part of the 2000 decade, the assessment of the stock was analytical using the age-based model XSA (ICES, 2002). Later, in view of the very low levels of landings, the assessment was based in the analysis of the trends of catch per unit effort (CPUE) and catch series (ICES, 2003).

The necessity of establishing reference points of the stock in relation with the maximum sustainable yield (MSY) has encouraged the use of new assessment methods for data-limited stocks (DLS) as FU 31 *Nephrops* (ICES, 2020b). In that sense ICES planned a workshop about SPiCT in February 2021 (WKMSYSPiCT) with two preparatory meetings in 2020.

Stochastic Surplus Production model In Continuous Time (SPiCT) separates random variability of stock dynamics from error in observed indices of biomass and also models the dynamics of the fisheries. This enables error in the catch process to be reflected in the uncertainty of estimated model parameters and management quantities.

Among data-limited methods (DLM), SPiCT could be a suitable tool for the analysis of FU 31 *Nephrops* stock since the stock meets the model assumptions and the model takes into account the long history of the fishery.

10.2 Input data for stock assessment (ToR 1 & 2)

Catch

Nephrops data were collected by the Spanish Institute of Oceanography since 1983 by month. Data were provided by ports authorities (sales notes) and crossed with the information provided by scientific personnel in the ports of landing. Since 2003, also logbook information was added (Table 10.1, Figure 10.2).

Table 10.1. FU 31 *Nephrops* catches series (t) (1983–2019).

Males + Females	FU 31 catches (t)
1983	63
1984	100
1985	128
1986	127
1987	118
1988	151
1989	177
1990	174
1991	109
1992	94
1993	101

Males + Females	FU 31 catches (t)
1994	148
1995	94
1996	129
1997	98
1998	72
1999	48
2000	34
2001	27
2002	26
2003	35
2004	29
2005	48
2006	37
2007	32
2008	20
2009	10
2010	9
2011	7
2012	10
2013	10
2014	4
2015	3
2016	3
2017	0
2018	3
2019	6

Abundance index

In the preparatory WKMSYSPiCT meeting that was held in October online, consisting in SPiCT learning sessions, it was recommended to use for the FU 31 SPiCT model the *Nephrops* index from bottom trawl scientific survey (SP-NSGFS) (Table 10.2, Figure 10.5).

Table 10.2. FU 31 SP-NSGFS survey *Nephrops* index (gramme/haul) (1983–2019). There was no survey in 1987. Smaller vessel and smaller gear in 1989. New vessel since 2013.

Males + Females	FU 31 *Nephrops* index (g/haul)
1983	97
1984	247
1985	319
1986	371
1987	No survey
1988	729
1989	105
1990	217
1991	178
1992	311
1993	245
1994	99
1995	124
1996	43
1997	104
1998	70
1999	82
2000	84
2001	107
2002	81
2003	108
2004	130
2005	86
2006	60
2007	79

Males + Females	FU 31 *Nephrops* index (g/haul)
2008	47
2009	39
2010	22
2011	65
2012	74
2013	103
2014	118
2015	176
2016	59
2017	50
2018	79
2019	55

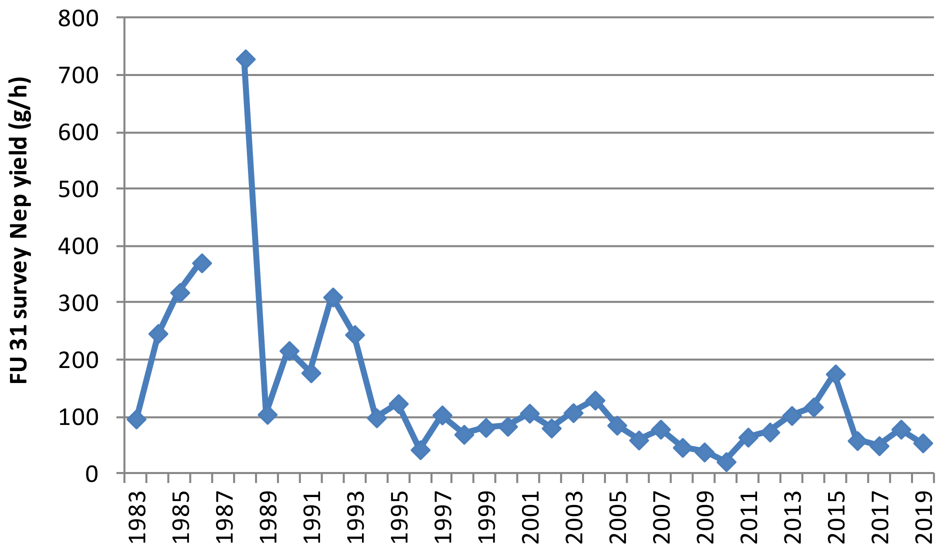

Figure 10.5. FU 31 SP-NSGFS Survey *Nephrops* index (gramme/haul) 1983–2019. There was no survey in 1987. Smaller vessel and smaller gear in 1989. New vessel since 2013.

In the online November preparatory meeting, which was focused on the input data evaluation, some issues were raised in order to check the reliability of the index.

The 1988 value was checked in the raw data and it was right, corresponds to hauls with very high *Nephrops* catch.

Regarding if the change since 1994 comes from a change of the survey design, in 1997 the survey first depth stratum changed from 30–100 m to 70–120 and the second from 100–200 m to 120–200 m. This could not affect to the index because in the whole survey time-series there was no

Nephrops at depths lower than 78 m, and the stratum and depth are not taken into account in the *Nephrops* index estimation. *Nephrops* index is the average of the yields in gramme by haul of the hauls within the *Nephrops* area.

Respect to the cause of the 1994 change could be related to a change of gear, the gear, the vessel and the duration of the hauls (30 minutes) have been the same since 1983 to 2012, with the exception of the year 1989, when a smaller vessel and smaller gear were used. After several calibrations, since 2013 a new vessel and gear are used. The gear was similar and there was no change relative to the *Nephrops* catch levels.

Regarding the number and distribution of the hauls along the survey period, they have been similar (Figure 10.6 and Figures 12.1.5–6abcd of 2020 ICES WGBIE report).

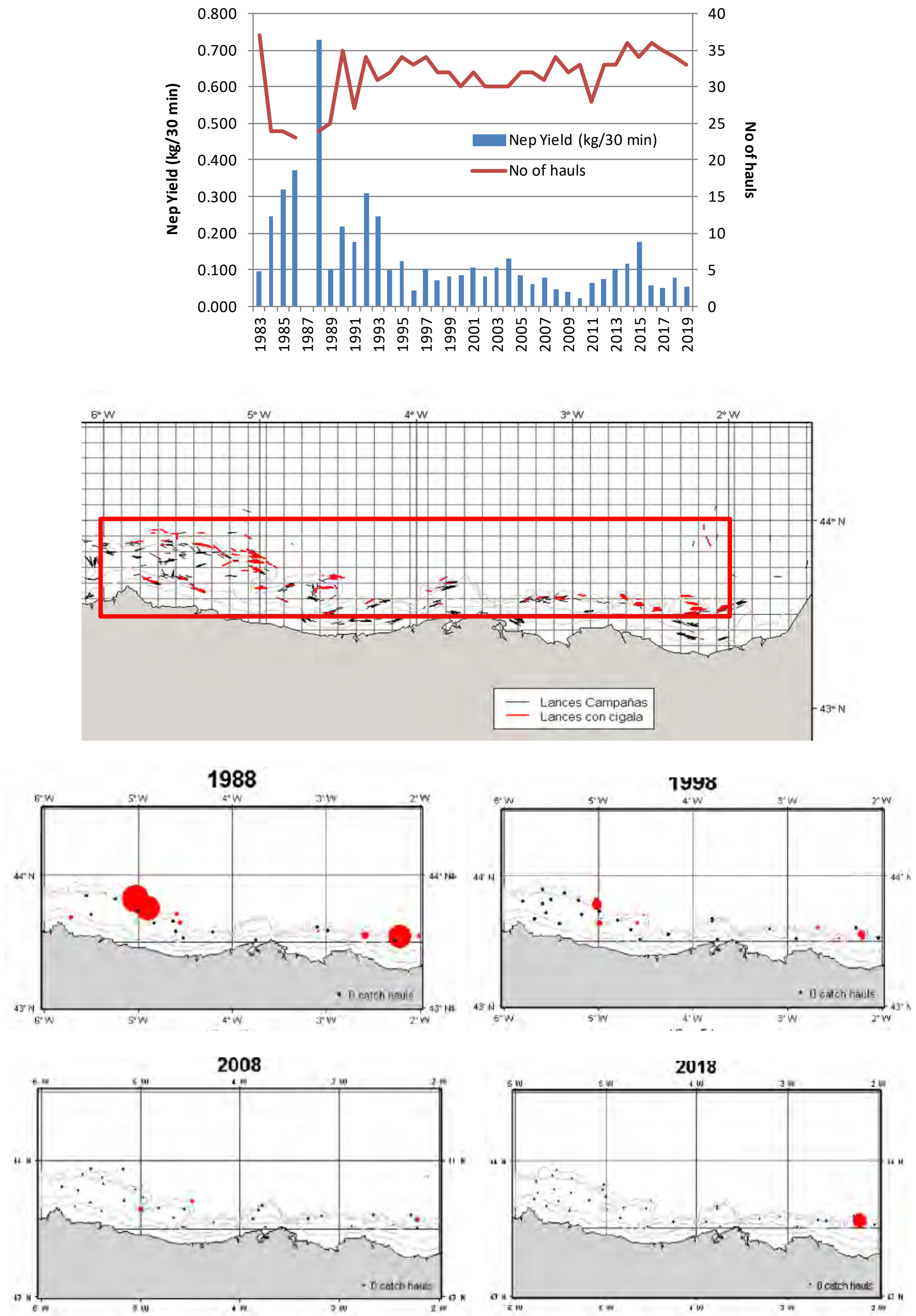

Figure 10.6. FU 31 SP-NSGFS Survey *Nephrops* index (gramme/haul) 1983–2019. Upper panel: No of hauls in the FU 31 along the time-series. There was no survey in 1987. In 1989 a smaller vessel and smaller gear were used. New vessel since 2013. Middle panel: Survey hauls (1983–2019). Lower panel (block of 4 plots): Example of survey distribution of hauls in four years.

Respect to the time of day of the hauls, the hauls in this survey have always been carried out during the daytime, never at nighttime.

A high decrease in the mid-1990s have been seen also in the *Nephrops* landings of 8c and 9a divisions (both divisions together and separately), in the FU 25 and FU 31 landings and especially in the percentage of males of FU 31 (Figure 10.7). Males fishing mortality is higher than that of females' since ovigerous females are in the burrows during eight months before the eggs hatching and the fishing gear cannot access them.

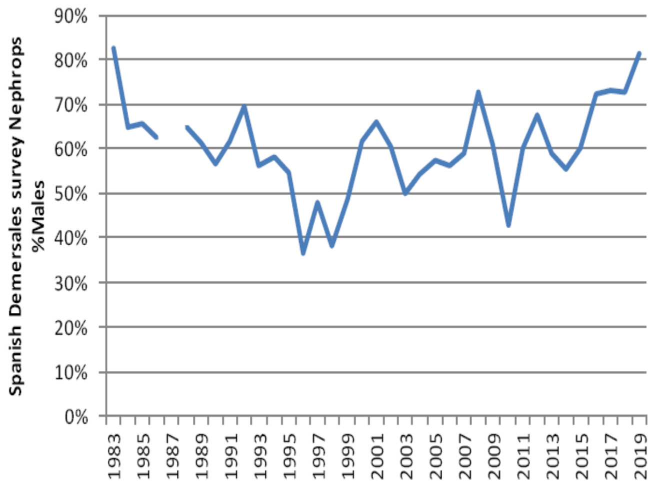

Figure 10.7. FU 31 SP-NSGFS Survey *Nephrops* percentage of males. 1983–2019.

Survey and fishery *Nephrops* mean sizes

Frequently the mean size of the individuals collected in a scientific survey is smaller than the mean size from the commercial fleet in the same area. In that cases trends observed in the scientific survey data could be reflected in the commercial catch one or two years later. The comparison of the survey and commercial mean sizes series of the FU 31 (Figure 10.8) shows that in this case it is preferable to introduce survey time-series in the model with one year more than the real.

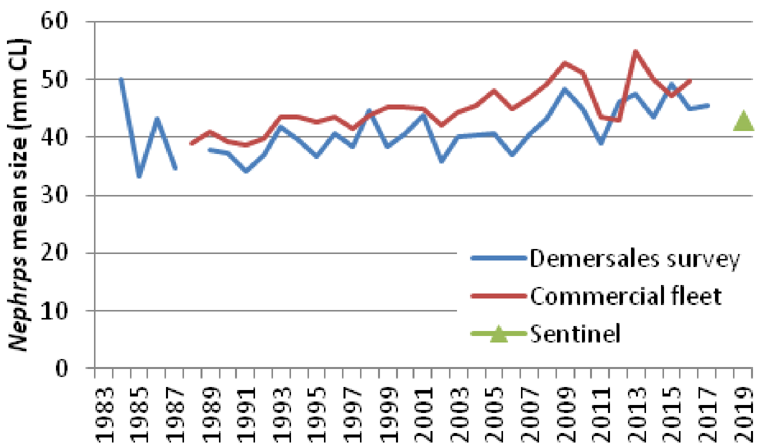

Figure 10.8. FU 31 *Nephrops* mean size (carapace length in mm) from the commercial fishery +0 years (red line), Sentinel fishery +0 years (green point) and SP-NSGFS survey +1 year (blue line) (1983–2019).

10.3 Stock assessment (ToR 3)

10.3.1 Exploratory assessments

In the October Learning sessions one run using SP-NSGFS *Nephrops* yield and two CPUEs (Avilés and Santander) as abundance indices was presented. The model converges but there were problems with the residuals. B_{2019}/B_{MSY} in this run was 1.8 and F_{2019}/F_{MSY} 0.03. In these sessions SP-NSGFS survey *Nephrops* yield was selected as unique index to use in the FU 31 model.

In the November Data evaluation meeting one run with the whole catch time-series, annual both sexes data and scaled index was presented (**Run a** in Table 10.3). Only runs with survey yield as unique index are presented in Table 10.3. In this run, no *Nephrops* explotation before 1983 was assumed (inp$priors$logbkfrac=c(0,1,1)) by mistake. The prior inp$priors$logn=c(log(2),0.5,1) was used in order to obtain the convergence of the model. There were not residuals problems but the index series was not lag in comparison with the catch series. B_{2019}/B_{MSY} in this run was 0.5 and F_{2019}/F_{MSY} 0.6.

Other runs (taking only the period of low catches since 1994 or only with males data or monthly or quarter data) were not done for the Data evaluation meeting since if we take only the last part of the catch time-series we would be ignoring the oldest levels of the fishery (stock catch decreased by 98% and the stock area by 49% along the time-series). Runs only with male data were not carried out since the Total Allowable Catch (TAC) is for the whole 8c division. Division 8c has two FUs, FU 25 and FU 31. If we work by sex, four models should be fit (FU 25 males, FU 25 females, FU 31 males and FU 31 females) and it would complicate the analysis. Monthly or quarter data were not used for the model since introduce very high volatility.

In the February meeting, four runs were presented. All of them with inp$dteuler=1/12. Table 10.4 show the diagnostics and estimates of those runs.

Run 0 was the initial run proposed to the WK. Run 0 was as run a but:

- with a lag of +1 year in the index time-series since trends in survey are seen in the catch one year later;
- with a medium level of *Nephrops* exploitation before 1983 (*inp$priors$logbkfrac <- c(log(0.5), 1, 1)*;
- several priors were introduced to process noise of F and catch, shape Shaefer production curve and increase uncertainty of survey index 1983–1994 period.

```
> inp$priors$logalpha <- c(0,0,0)
> inp$priors$logbeta <- c(0,0,0)
> inp$priors$logsdf <- c(log(3), 0.5, 1)
> inp$priors$logsdc <- c(log(0.1), 0.2, 1)
> inp$priors$logn <- c(log(2),0.5,1)
> inp$stdevfacI <- list(c(rep(2, 12), rep(1, length(inp$timeI[[1]]) - 12)))
```

There were not residuals problems. B_{2019}/B_{MSY} in this run was 0.3 and F_{2019}/F_{MSY} 0.6.

Run 1 was as run 0 but:

- with inp$priors$logbkfrac <- c(log(0.5), **0.2**, 1);
- without inp$priors$logn <- c(log(2),0.5,1);
- with inp$priors$logr <- c(log(0.2), 0.2, 1).

B_{2019}/B_{MSY} in this run was 0.2 and F_{2019}/F_{MSY} 0.4.

Run 2 was as run 1 but:

- with inp$priors$logn <- c(log(2),0.5,1).

B_{2019}/B_{MSY} in this run was 0.2 and F_{2019}/F_{MSY} 0.3.

Run 3 was as run 1 but:

- with inp$phases$logn=-1.

B_{2019}/B_{MSY} in this run was 0.5 and F_{2019}/F_{MSY} 0.25.

Table 10.3. Characteristics of the FU 31 SPiCT runs carried out with SP-NSGFS *Nephrops* yield as index.

		Catch				Index				Priors										
Meeting	Run	Catch period	Catch time unit	2017-2019 catches	Sex	Index Hauls from FU	Index 1988 outlier	Index scaled	Index lag	Previous Stock explotaition (BK frac)	logn	logalpha	logbeta	logsdf	logsdc	stdevfacI list(c(rep(2, 12), rep(1, length(inp$timeI[[1]]) - 12)))	log r	Convergence	Normality	Comment
Nov 20	a	1983-2019	Ye	R	B	Rc	NS	Y	N	c(0,1,1)	c(log(2),0.5,1)	-	-	-	-	-	-	Y	Y	No lag, wrong BK frac
Feb 21	0	1983-2019	Ye	R	B	Rc	NS	Y	Y	c(log(0.5),1,1)	c(log(2),0.5,1)	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	-	Y	Y	
Feb 21	1	1983-2019	Ye	R	B	Rc	NS	Y	Y	c(log(0.5),0.2,1)	-	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	c(log(0.2),0.2,1)	Y	Y	Sensitivity run
Feb 21	2	1983-2019	Ye	R	B	Rc	NS	Y	Y	c(log(0.5),0.2,1)	c(log(2),0.5,1)	c(0,0,0)	c(0,0,0)	c(log(3),0.5,1)	c(log(0.1),0.2,1)	Y	c(log(0.2),0.2,1)	Y	Y	Sensitivity run
Feb 21	**3**	**1983-2019**	**Ye**	**R**	**B**	**Rc**	**NS**	**Y**	**Y**	**c(log(0.5),0.2,1)**	**inp$phases$logn=-1**	**c(0,0,0)**	**c(0,0,0)**	**c(log(3),0.5,1)**	**c(log(0.1),0.2,1)**	**Y**	**c(log(0.2),0.2,1)**	**Y**	**Y**	**FINAL RUN**

- = Default, B=Both, N=No, NS=Not substituted, R=Real, Rc=Rectangles, Y=Yes, Ye=Year
All runs with SP-NSGFS survey Nephrops yield as index

Table 10.4. Diagnostics & estimates of FU 31 runs.

Run	All finite	bmsyk	magnitude B/Bmsy, F/Fmsy	sensitivity to initial values	corr values > 0.8	Shapiro Catch	Shapiro Survey	rho B/Bmsy	rho F/Fmsy	n	r	B2019/Bmsy	b/tr	b/blim	F2019/Fmsy
0	Y	0.5	(2,1)	ok	none	0.896	0.413	0.442	-0.289	1.928	0.041	0.32	0.64	1.07	0.62
1	Y	0.7	(1,1)	ok	0.81:logK~logn -0.86:logq~logn	0.882	0.403	0.584	0.023	5.559	0.198	0.21	0.42	0.7	0.41
2	Y	0.6	(0,0)	ok	none	0.814	0.190	0.762	-0.051	3.62468	0.186	0.24	0.49	0.81	0.34
3	Y	0.5	(1,1)	ok	0.85:logK~logm	0.939	0.140	0.015	0.226	fixed=2	0.184	0.48	0.96	1.59	0.25

Catch: 1983-2019; survey: 1983-2019 (scaled to 1) (dteuler=1/12)

3 = FINAL RUN

10.3.2 Final assessment

WKMSYSPiCT accepted the SPiCT run 3 (Table 10.3 and Table 10.4) for the assessment of FU 31. Run 3 uses the whole catch time-series (1983–2019), the whole SP-NSGFS survey index time-series (1983–2019) with annual and both sexes data and the recorded catches for 2017–2019. The index was calculated with all the survey hauls in the FU 31 statistical rectangles, the index 1988 outlier was not substituted nor deleted and the index was scaled. The index time-series was lag 1 year respected to the catch time-series. A medium *Nephrops* level of exploitation before 1983 was assumed, and several priors were used in order to process noise of F and catch, fix n=2 to shape Shaefer production curve, increase uncertainty of survey index 1983–1994 period and fix r=0.2 (Table 10.3 and Table 10.4). Fit, diagnostic and retrospective pattern are shown in Figure 10.10, Figure 10.11 and Figures 10.12 and 10.13, respectively. Results of the model are shown in Table 10.5 and Table 10.6. Below is shown the R code used:

```
##Scale survey index to mean 1 (for better numerical stability)
> mstd=function(x) x/mean(x,na.rm=TRUE)
> fu31$DEM = mstd(fu31$DEM)
#Create the inp object for the model
> inp = list(timeC=fu31$TC, obsC=fu31$C,
+            obsI=list(obsI2=fu31$DEM),
+            timeI=list(timeI2=fu31$TD+0.8333333))  #survey time set to October
> ## -- Time step & management period
> inp$dteuler=1/12
> inp$maninterval = c(2021, 2022)   #management starts with one intermediate year (i.e. 2020)
> inp$maneval = 2022
> inp=check.inp(inp)
> inp$dtc
> ## -- Priors (final run)
> inp$priors$logbkfrac=c(log(0.5),0.2,1)       #medium initial depletion
> inp$phases$logn= -1                          #n=2 (Schaefer production curve)
> inp$priors$logalpha=c(0,0,0)                 # deactivate
> inp$priors$logbeta=c(0,0,0)                  # deactivate
> inp$priors$logsdf=c(log(3), 0.5, 1)          # process noise of F
> inp$priors$logsdc=c(log(0.1), 0.2, 1)        # observation noise Catch
> inp$stdevfacI=list(c(rep(2,12),rep(1,length(inp$timeI[[1]])-12))) #higher uncertainty survey period 1984:1995
> inp$priors$logr=c(log(0.2),0.2,1)            #intrinsic biomass growth
```

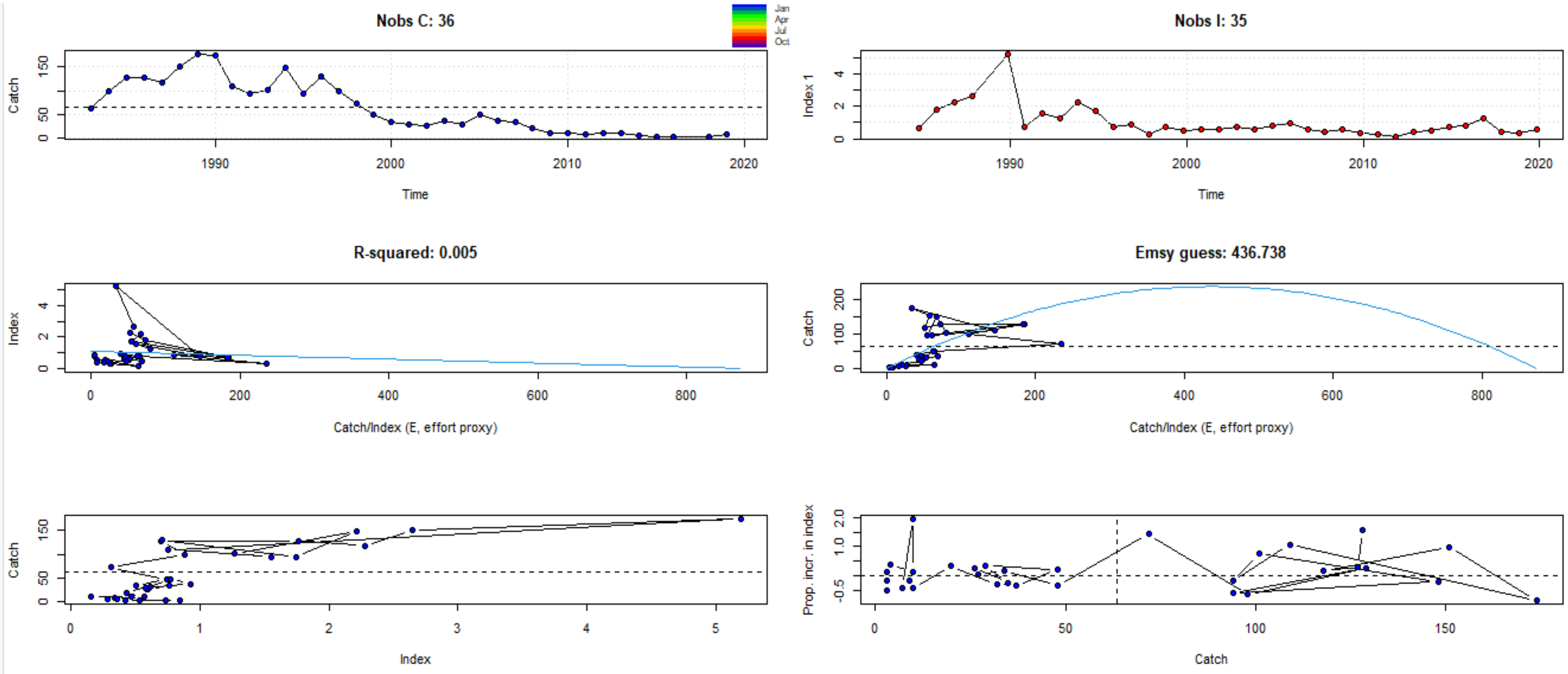

Figure 10.9. Catch and Index time-series, Index vs. Catch/Index, Catch vs Catch/Index, Catch vs. Index and Proportional Increment in Index vs. Catch.

Table 10.5. Results of the model run3.

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 65.852565
Euler time step (years):  1/12 or 0.08333
Nobs C: 36,  Nobs I1: 35

Priors
      logn  ~  dnorm[log(2), 2^2]
      logr  ~  dnorm[log(0.2), 0.2^2]
 logbkfrac  ~  dnorm[log(0.5), 0.2^2]
    logsdf  ~  dnorm[log(3), 0.5^2]
    logsdc  ~  dnorm[log(0.1), 0.2^2]

Fixed parameters
   fixed.value
 n           2

Model parameter estimates w 95% CI
           estimate       cilow        ciupp    log.est
 alpha     1.5212320   0.5767085    4.0126796  0.4195205
 beta      0.1898032   0.1152972    0.3124556 -1.6617674
 r         0.1837407   0.1257583    0.2684567 -1.6942296
 rc        0.1837407   0.1257583    0.2684567 -1.6942296
 rold      0.1837407   0.1257583    0.2684567 -1.6942296
 m        77.4350062  40.3238609  148.7005471  4.3494390
 K      1685.7451087 830.8295344 3420.3605601  7.4299629
 q         0.0018492   0.0007094    0.0048206 -6.2929946
 sdb       0.2172527   0.1077271    0.4381324 -1.5266941
 sdf       0.5038557   0.3692948    0.6874471 -0.6854653
 sdi       0.3304918   0.2250011    0.4854412 -1.1071736
 sdc       0.0956334   0.0659182    0.1387440 -2.3472327
```

```
Stochastic reference points (Srp)
        estimate       cilow         ciupp   log.est rel.diff.Drp
 Bmsys 723.939895 346.0040980 1514.6900718  6.584708   -0.1642853
 Fmsys   0.080098   0.0537622    0.1193346 -2.524504   -0.1469745
 MSYs   56.586044  26.2595431  121.9358775  4.035762   -0.3684471

States w 95% CI (inp$msytype: s)
                  estimate       cilow       ciupp    log.est
 B_2019.92      346.2856922 129.5148608 925.8688912  5.8472641
 F_2019.92        0.0198811   0.0065951   0.0599317 -3.9179876
 B_2019.92/Bmsy   0.4783349   0.1589296   1.4396575 -0.7374442
 F_2019.92/Fmsy   0.2482091   0.0831596   0.7408376 -1.3934836
```

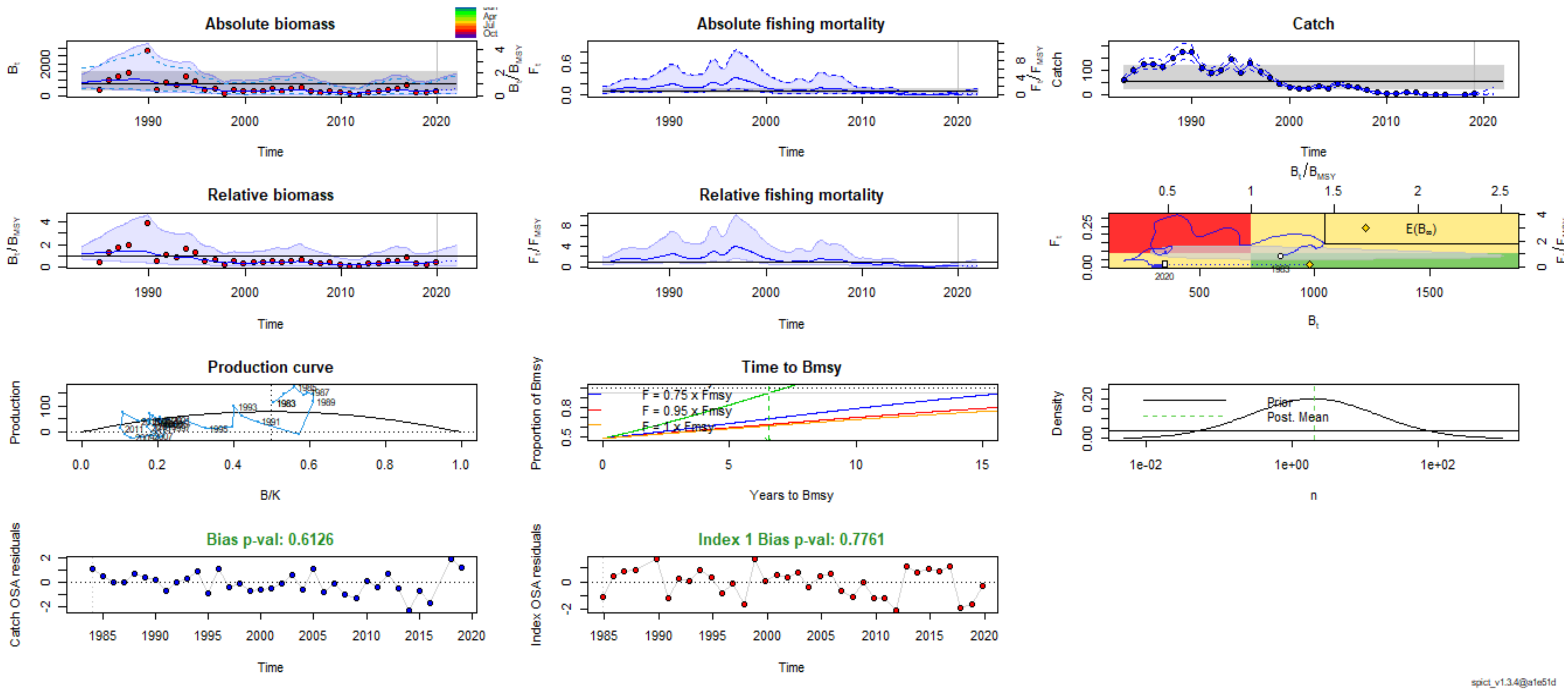

Figure 10.10. Results of the model run 3 fit.

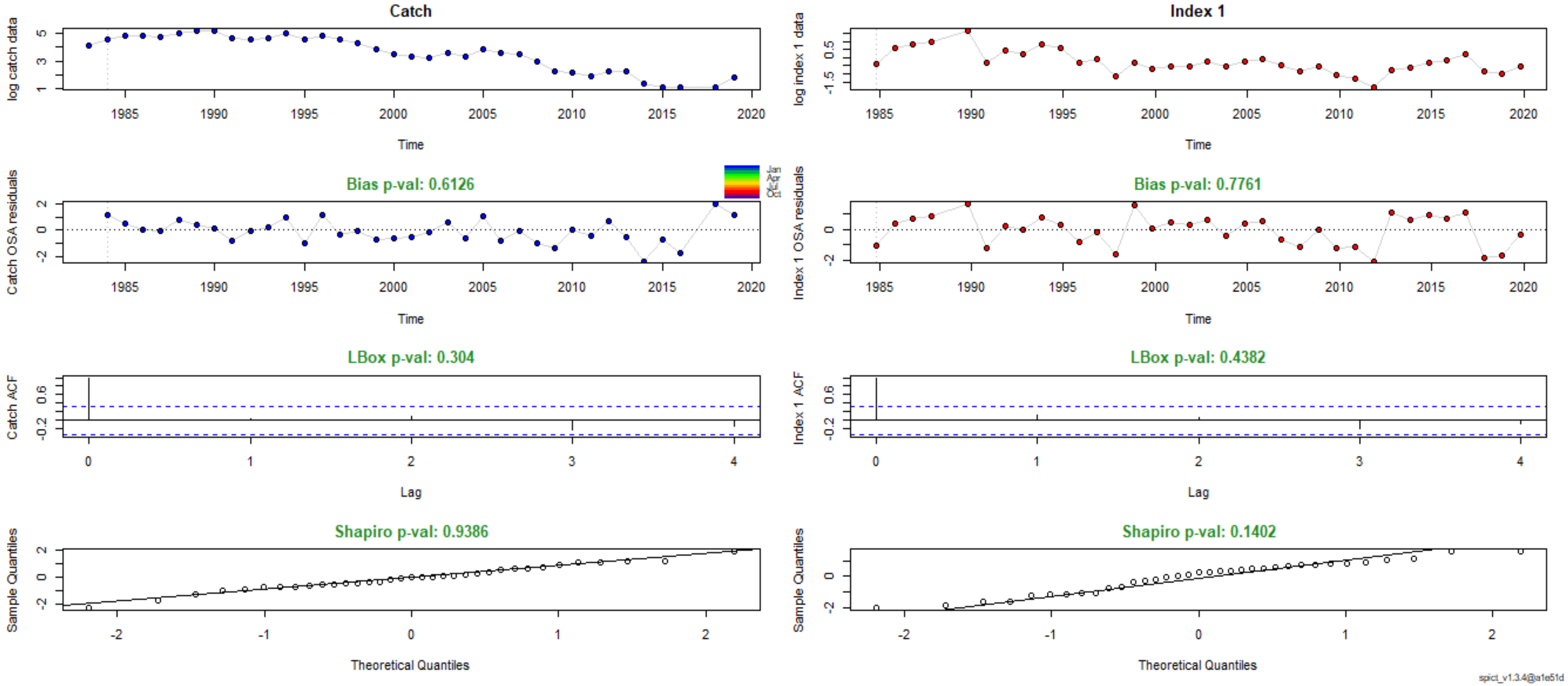

Figure 10.11. Model diagnostic.

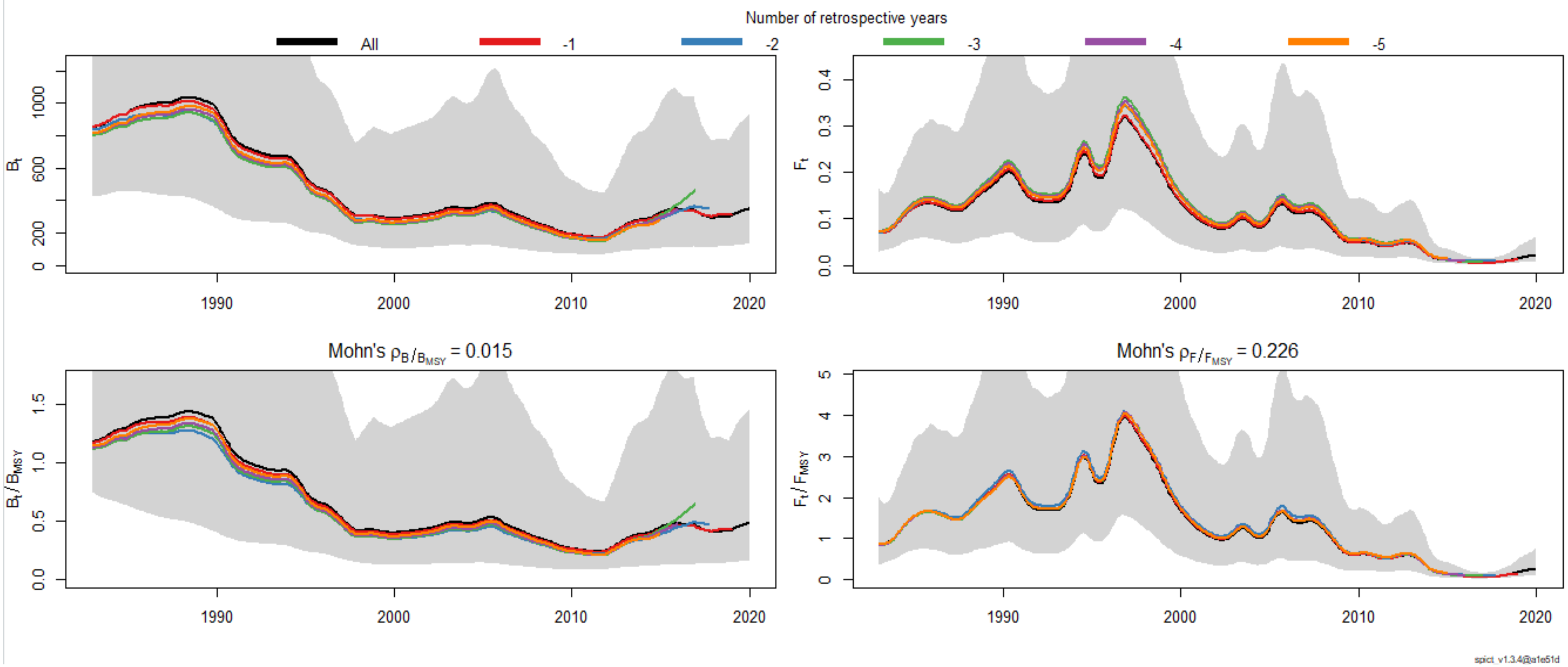

Figure 10.12. B_t, F_t, B_t/B_{MSY} and F_t/F_{MSY} retrospective analysis.

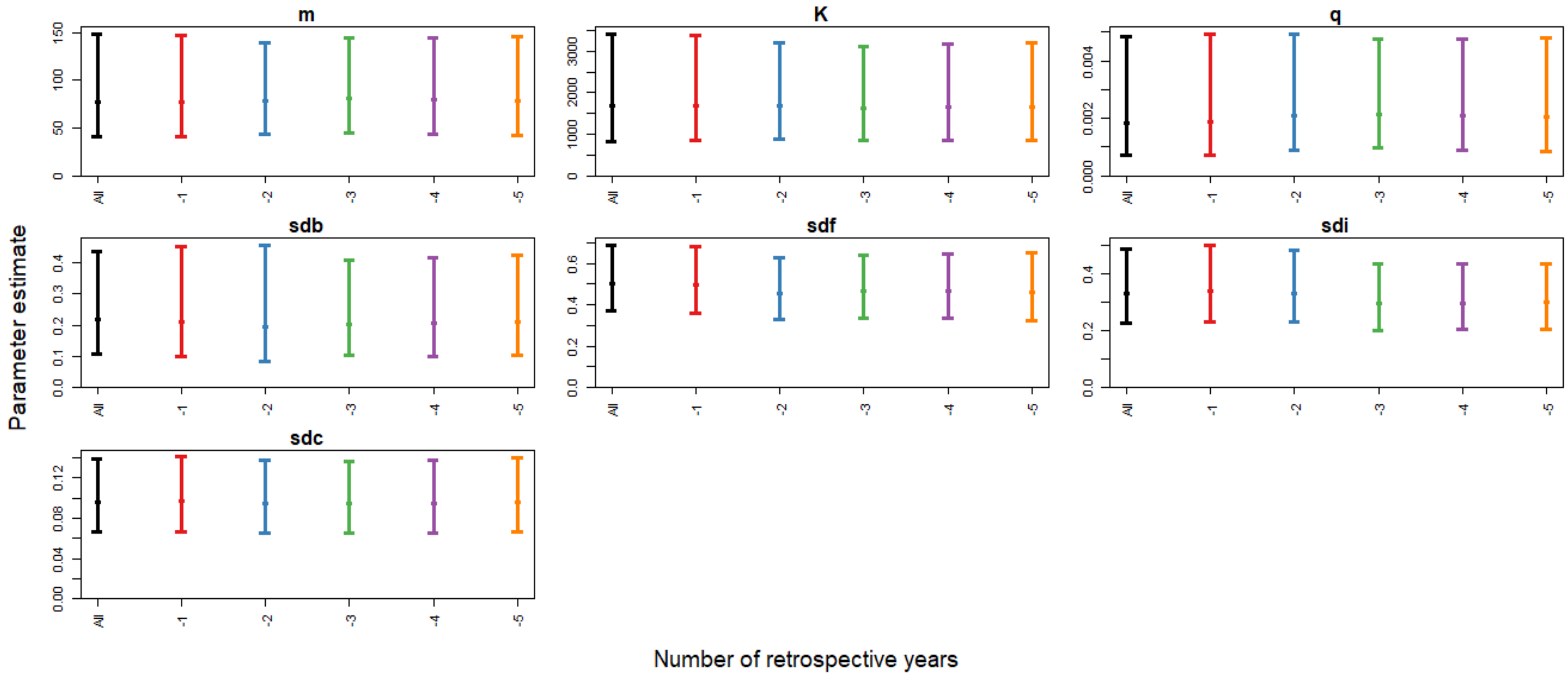

Figure 10.13. Parameter estimate vs number of retrospective years.

Table 10.6. B_{MSY}, $B_{trigger}$, B_{lim}, B_2019/B_{MSY}, B_2019/$B_{trigger}$, B_2019/B_{lim}.

```
> Bmsy; Btrigger; Blim
[1] 723.9399
[1] 361.9699
[1] 217.182
```

```
> round(B_2019/Bmsy,2);round(B_2019/Btrigger,2); round(B_2019/Blim,2)
[1] 0.48
[1] 0.96
[1] 1.59
```

10.4 Catch forecast (ToR 4)

Catch forecast was carried out using SPiCT version 1.3.4 and R code presented during the WKMSYSPiCT. Forecast was conducted using an intermediate year. Results for the four different scenarios agreed in the WKMSYSPiCT are show in the Table 10.4. Harvest control rules plots are also presented in Figure 10.14.

Table 10.4. Catch forecast table for FU 31 with management scenarios.

```
SPiCT timeline:

      Observations            Intermediate            Management
    1983.00 - 2020.00       2020.00 - 2021.00      2021.00 - 2022.00
  |-----------------------| ----------------------| ----------------------|

Management evaluation: 2022.00

Predicted catch for management period and states at management evaluation time:

                         C B/Bmsy F/Fmsy
1. F=0                 0.0   0.60   0.00
2. F=Fsq               8.0   0.59   0.25
3. F=Fmsy             31.5   0.55   1.00
4. F=Fmsy_C_fractile  24.3   0.56   0.76

95% confidence intervals for states:

                     B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo F/Fmsy.hi
1. F=0                    0.18      1.96      0.00      0.00
2. F=Fsq                  0.18      1.95      0.04      1.50
3. F=Fmsy                 0.16      1.91      0.17      6.03
4. F=Fmsy_C_fractile      0.17      1.92      0.13      4.61
```

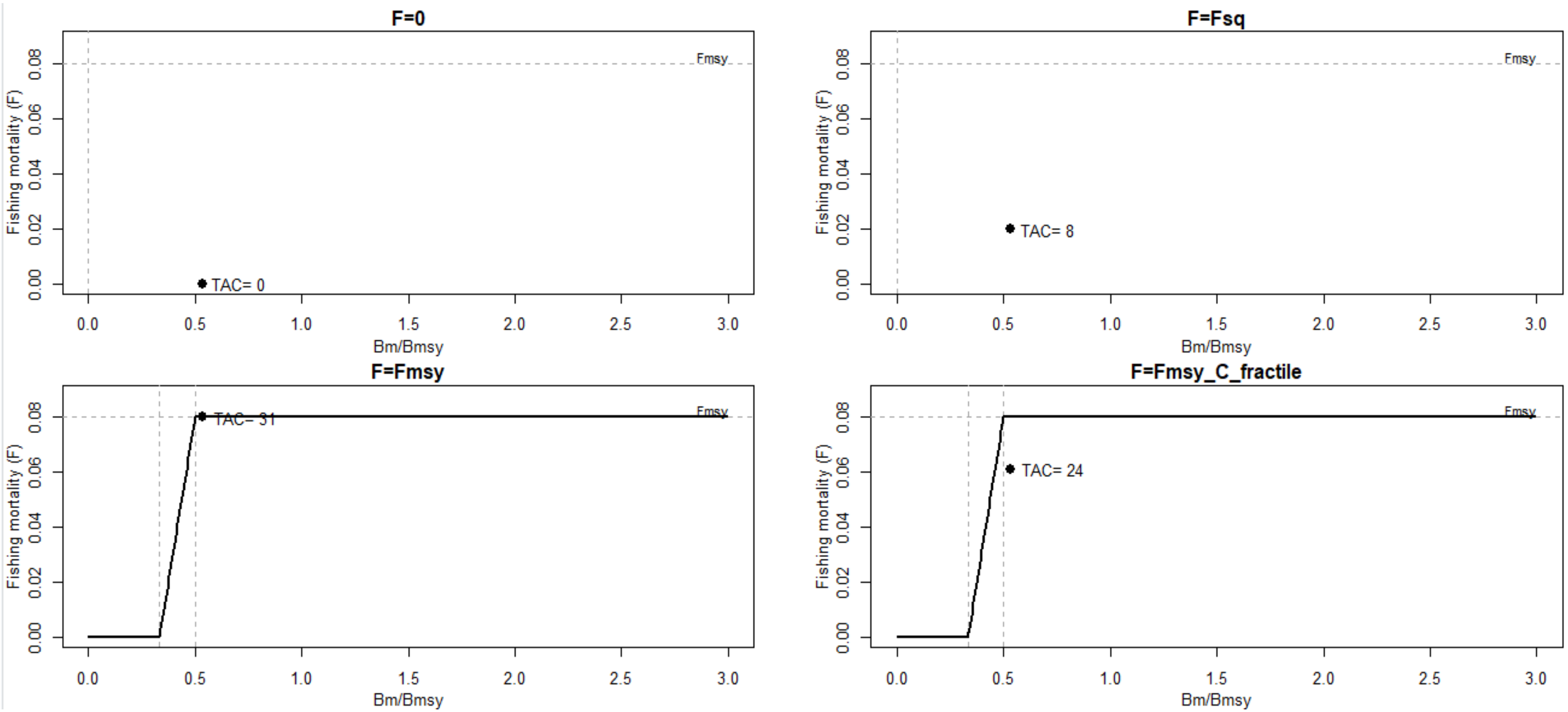

Figure 10.14. Harvest control rules plots for different scenarios for *Nephrops* FU 31. Fishing mortality (F) vs B_m/B_{ms} for the scenarios F=0, F=F_{sq}, F=F_{MSY} and F=F_{MSY} C fractile.

10.5 Future considerations/recommendations

Despite fishing mortality (F) in the last year of the time-series (2019) is below F_{MSY} (25%), 2019 biomass is 48% of the B_{MSY}. The stock has an extremely low biomass, along the time-series the catch has decreased by 98% and the area of the stock by 49%. Therefore, the management of the stock should be established under a precautionary approach.

10.6 Reviewers report

Reviewers report is presented for both FU 25 and 31 in Section 9.6.

10.7 References

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ICES. 2020b. Workshop on Methodologies for *Nephrops* Reference Points (WKNephrops; outputs from 2019 meeting). ICES Scientific Reports. 2:3. 106 pp. http://doi.org/10.17895/ices.pub.5981

11 Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (fle.27.3a4)

11.1 Introduction

Flounder is a euryhaline flatfish: the life cycle of each individual usually includes marine, brackish, and freshwater habitats. It has a coastal distribution in the Northeast Atlantic, ranging from the White Sea and the Baltic in the north, to the Mediterranean and Black Sea in the south. Flounder can live in low salinity water but they reproduce in water of higher salinity. There is no information about stock identity and possible stock assessment areas in the North Sea, Skagerrak and Kattegat. Within the North Sea there may exist a number of subpopulations (ICES, 2013a).

Flounder feeds on a wide variety of small invertebrates (mainly polychaete worms, shellfish, and crustaceans), but locally the diet may include small fish species like smelt and gobies. The most intensive feeding occurs in the summer, while food is sparse in the winter. In the North Sea, Skagerrak and Kattegat flounder spawn between February and April. The adults move further offshore to the 25–40 m deep spawning grounds, the most important of which are situated along the coasts of Belgium, the Netherlands, Germany, and Denmark. During autumn, both mature and immature flounder withdraw from the inshore and estuarine feeding areas. Juvenile flounder migrate into coastal areas, where they spend the winter.

Flounder is of relatively little commercial importance in the North Sea and in the Skagerrak and Kattegat. Flounder is mainly a bycatch in the fishery for commercially more important flatfish such as sole and plaice and in the mixed demersal fisheries. The North Sea flounder stock was assessed until 2013 in the Working Group on Assessment of New MoU Species (ICES, 2013a). Because only official landings and survey data were available, flounder was defined as a category 3 species according to the ICES guidelines for data-limited stocks (ICES, 2012). Biennial advice for flounder was given since 2013 by ICES (ICES, 2013b) based on survey trends. Since 2015, flounder was included in the official data call for the WGNSSK and discard estimates were included into the assessment. In 2017 a combined TAC for dab and flounder was removed (EU COM, 2017/595), and North Sea flounder has become a non-target species with no TAC since then. ICES has not been requested to provide advice on fishing opportunities for flounder since then. Still, biennial advice is requested for this stock to evaluate the stock status and exploitation status.

During a benchmark assessment for the North Sea Flounder stock, a SPiCT model (Pedersen and Berg, 2017) for flounder was accepted to estimate MSY proxies for this stock (ICES, 2018a). The model was updated during the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) in 2019 with the most recent catch and survey data. Unfortunately, updating the SPiCT assessment model with the 2017 and 2018 data, increased the uncertainties to unacceptable levels and the assessment was rejected by the Working Group (ICES, 2019). Details on the settings of this model are displayed in Table 1.

During the data evaluation workshop following issues were addressed for the flounder stock:

- Investigate the inclusion of additional survey information, DYFS Q3;
- try different uncertainties also on survey indices and use longer time-series of Q3 index;
- try different priors on B/K; sensitivity analysis (*to be done*);
- provide sensitivity analysis on prior sd log(n) (*to be done*).

11.2 Input data for stock assessment (ToR 1 & 2)

Official landings and catch data time-series

Landings data may have been misreported in previous years. However, the amount of misreporting is not known. In addition, the official landings may not reflect the total catches, because flounder is often discarded, and discarding is influenced by the prices and the availability of other, commercially more important species and therefore cannot be estimated for years without observations.

The largest part of official landings is reported for Subarea 4 (Figure 11.1), especially for the more recent years. From 1950 to 1970 annual landings from the North Sea decreased and fluctuated between 1971 and 1983 without any clear trend. The apparent decrease in official landings between 1984 and 1997 in Subarea 4, is due to unreported landings by the Netherlands for that period (Figure 11.1a). Further, there seem to be an issue with Danish and German official landings in Subarea 4, which drastically dropped after 1997. At least the drastic decline in Danish landings could be explained by the combined TAC for dab and flounder, which was established in 1998, i.e. that before 1998 partly combined dab and flounder landings may have been reported by the Danish fishery. Another reason maybe misreporting to flounder from other quota species from the fishery in area 4 before the TAC came in force in 1998. During the last two decades, landings declined considerably in Subarea 4 (Figure 11.1a) with the lowest observed landing in 2017. Also in Division 3.a, a steady decline in landings is observed from mid of the 1980s with the lowest observed official landing in 2015 (Figure 11.1b).

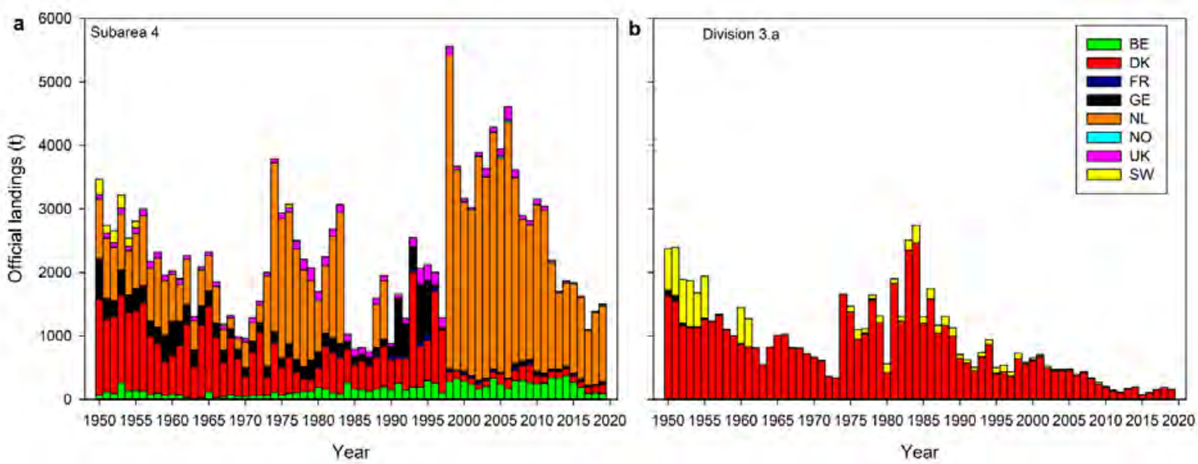

Figure 11.1. Official flounder landings for Subarea 4 (a) and Division 3.a (b) by country.

A catch time-series, landings and discards, is available for the years 2002–2019 (Figure 11.2). The amount of total discards was estimated by a raising procedure using the InterCatch tool. This procedure calculates a discard ratio from reported landings and discards for specific fishing fleets which are then used to raise discards for fleets for which only landings are reported. Prior to 2002 no discard data are available, and landings data are partly incomplete. Therefore, a reconstructed catch time-series (1983–2001) was used in combination with the InterCatch time-series as input for the SPiCT model. A detailed description of the method to reconstruct catches back in time can be found in the benchmark report (ICES, 2018a; Flounder WD4).

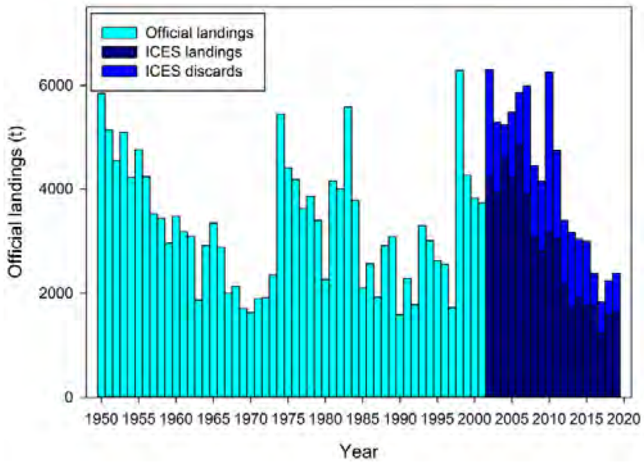

Figure 11.2. Official flounder landings (1950–2001), ICES landings and ICES discards (InterCatch, 2002–2019) for Subarea 4 and 3.a combined.

Survey data

Several surveys in the North Sea, Skagerrak and Kattegat provide information on distribution, abundance and length composition of flounder. The most relevant survey for flounder is probably the International Bottom Trawl Survey IBTS in quarter 1 because it covers the whole distribution area of the stock and shows even a higher catchability compared to the beam trawl surveys conducted in quarter 3. However, the IBTSQ1 uses a bottom trawl which is not very well suited to catch demersal flatfishes. The beam trawl surveys (BTS) use a beam trawl and are designed for catching flatfish. However, they are carried out in quarter 3, in a time of year in which flounder still maybe distributed in more coastal, shallow and brackish waters.

Two survey indices are used for the flounder assessment: the IBTS quarter 1 index and a combined quarter 3 index (combining IBTS, BTS, and the Sole Net Survey), both indices modelled with the deltaGAM method (Berg *et al*., 2014). For both indices an index area was defined (Figure 11.3) which is restricted to the southeastern part of the North Sea and Division 3.a. In quarter 3, four gear types are used in the different beam trawl surveys (BT8, BT7, BT6, and BT4) and the GOV in the IBTS survey. Therefore, a gear effect was included to model a combined quarter 3 index for flounder. Details on the method can be found in the benchmark report (ICES, 2018a; Flounder WD1).

The IBTS quarter 1 index shows some higher values at the beginning of the time-series (Figure 11.4a). Since 2000, the index is fluctuating without any clear trend. Since 2015, the index decreased. The combined quarter 3 index shows high variability with no clear trend over the whole time-series (Figure 11.4b).

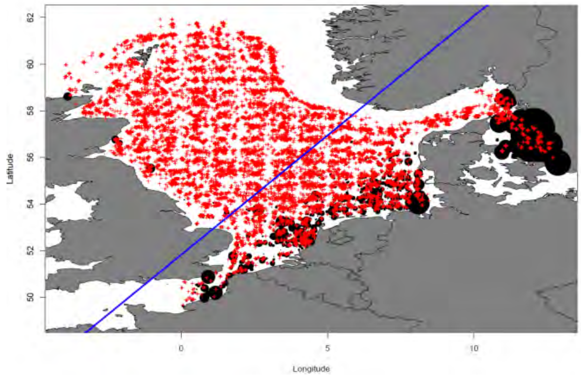

Figure 11.3. Flounder in Subarea 4 and Division 3a. IBTS quarter 1 hauls (1983–2016). Red crosses display hauls with zero flounder caught, black bubbles display flounder catches. The blue line displays the border of the index area which includes all stations east of this line.

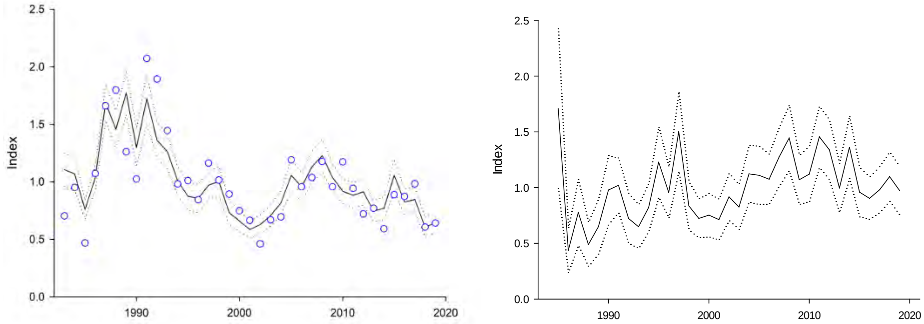

Figure 11.4. Flounder in Subarea 4 and Division 3.a: IBTS Quarter 1 biomass index (left panel; black line = deltaGAM index, blue dots = old mature biomass index used in previous assessments) and combined quarter 3 biomass index (right panel).

In addition to the previously used indices, a Demersal Young Fish Survey biomass index was constructed (2002–2019). The DYFS covers coastal areas, including the Wadden Sea and the river estuaries of the German Bight. However, the inclusion of this index into the assessment did not change the SPiCT results compared to the previous assessment run.

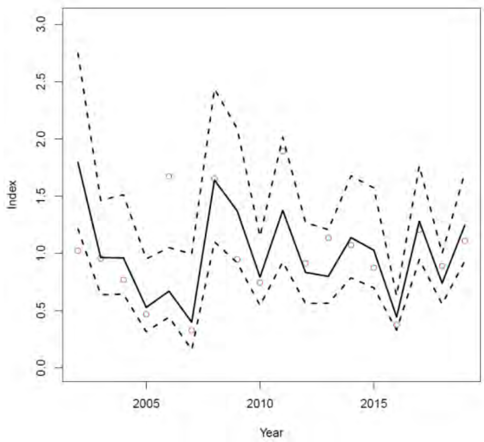

Figure 11.5. Flounder in Subarea 4 and Division 3.a: Demersal Young Fish Biomass Index with ESB correction.

11.3 Stock assessment (ToR 3)

The SPiCT was used to assess the stock status and exploitation status relative to MSY proxies for flounder. Table 11.1 summarizes the input data and settings which were used for the assessment which was accepted by a previous benchmark on the flounder stock (ICES, 2018).

Table 11.1. Flounder in Subarea 4 and Division 3.a. SPiCT settings and input data for the SPiCT model.

Setting/Data	Values/Source
Catch time-series	Truncated catch time-series 1983–2019: InterCatch data 2002–2019; Reconstructed Dutch landings for period 1984–1997, applying average Dutch landing proportion (0.64, 1974–1983); applying average discard ratio (0.48, 2002–2016) to estimate total catch
Combined Q3 survey index 2002–2019	International Bottom Trawl Survey (IBTS); North Sea Beam Trawl Surveys (BTS); Sole Net Survey (SNS); DATRAS
IBTS Q1 survey index	International Bottom Trawl Survey 1983–2020, DATRAS
SPiCT settings	Different uncertainties applied to catch input data for different periods: 4 -> 1983 1997 3 -> 1998–2001 2 -> 2002–2010 1 -> 2011–2019 Priors on sd log(n) set to 1

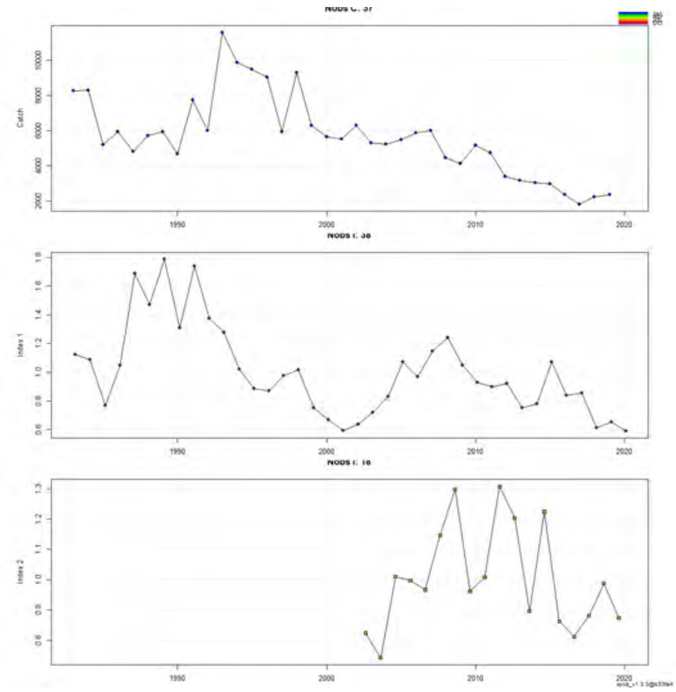

Figure 11.6. Flounder Subarea 4 and Division 3.a: Input data for the previous SPiCT assessment.

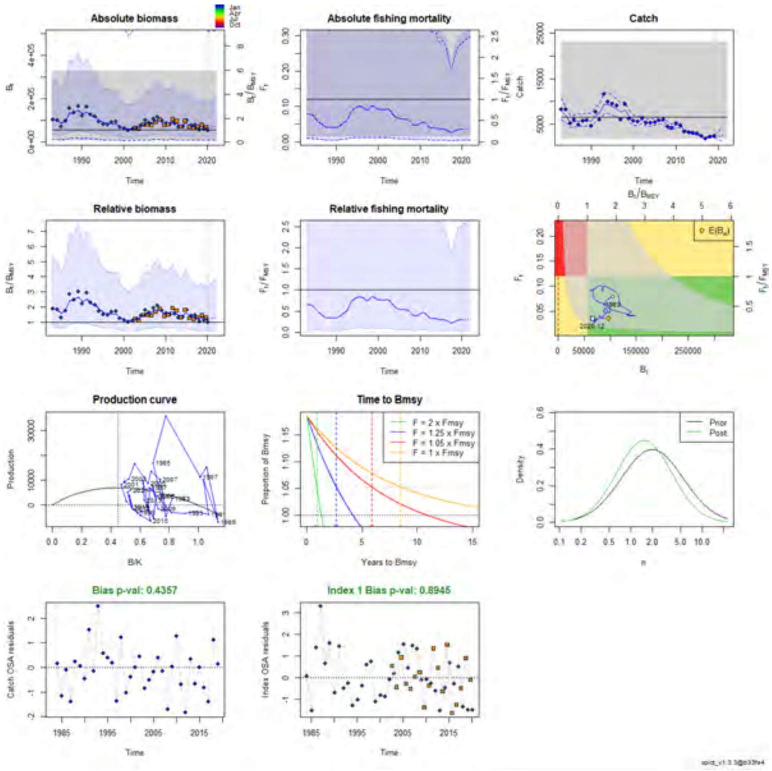

Figure 11.7. Flounder Subarea 4 and Division 3.a: Results of the previous SPiCT assessment.

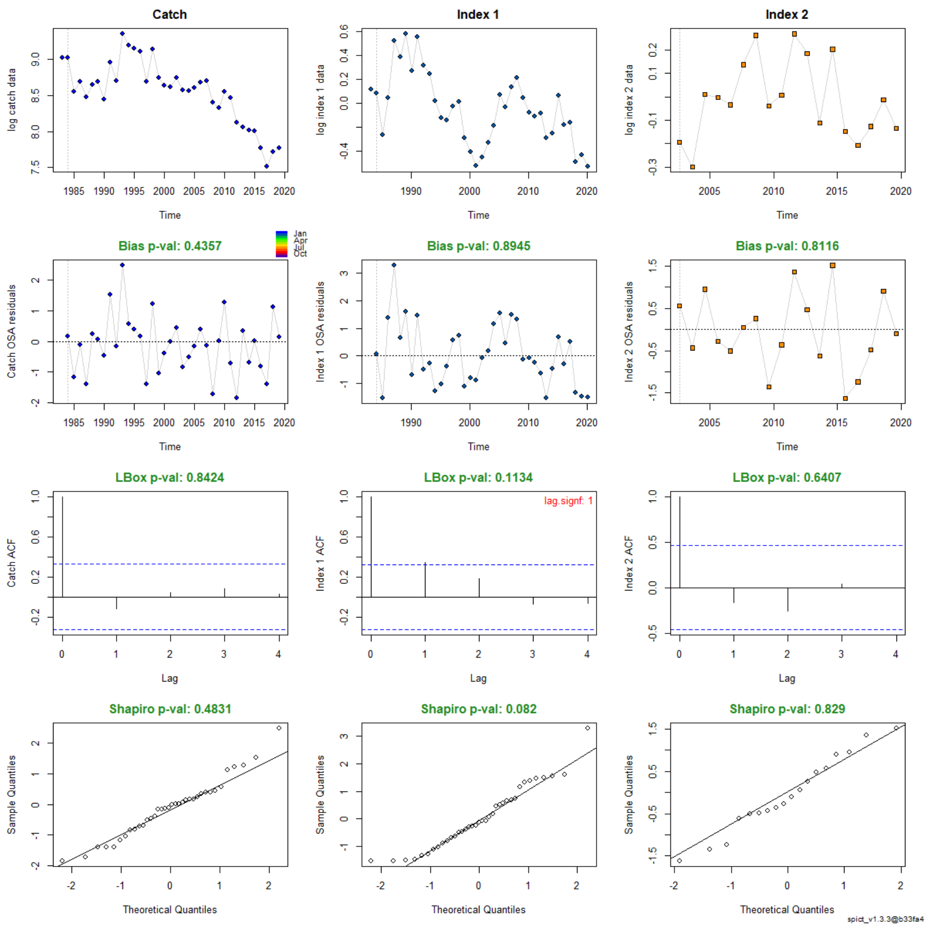

Figure 11.8. Flounder Subarea 4 and Division 3.a: Diagnostics of the previous SPiCT assessment.

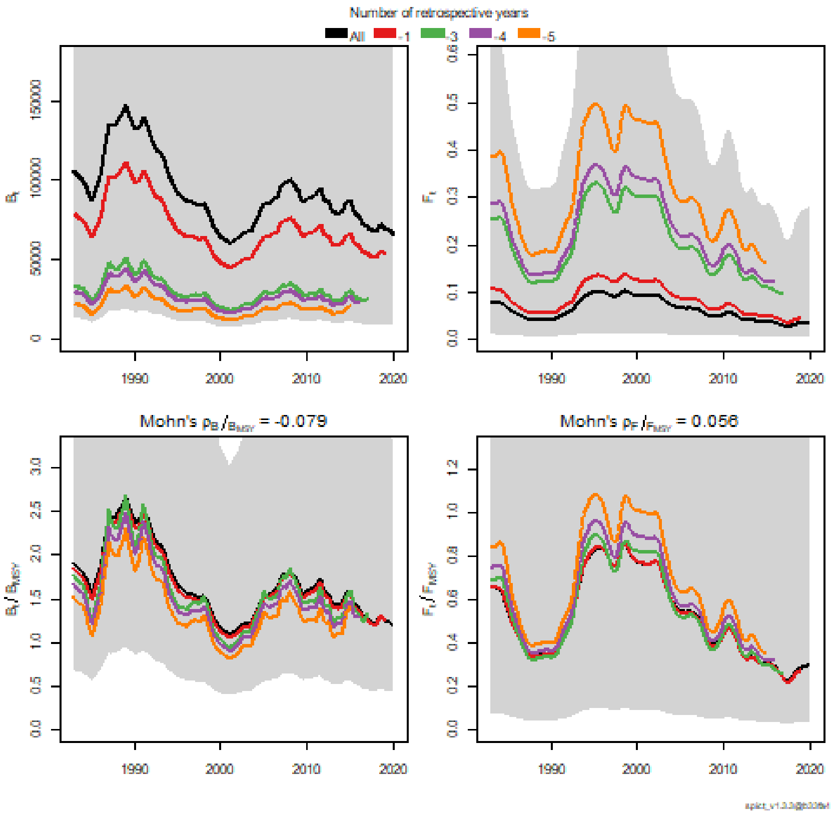

Figure 11.9. Flounder Subarea 4 and Division 3.a: Retrospective analyses of the previous SPiCT assessment.

11.3.1 Exploratory assessments

	Catch data	Reconstruction of catch	IBTS Q1 Biomass Index	combined Q3 Iindex (IBTS, BTS, SNS)	DYFS biomass index	uncertainties	priors	converged
Base run from current SPiCT	InterCatch 2002 - 2019, reconstructed catch time series	InterCatch, raised discards; reconstructed Dutch landings for time period 1984-1997 by applying average Dutch landings proportion 1974 - 1983 (0.64)	1983 - 2020	2002 - 2019		Different uncertainties were applied on catch for different time periods: + (4) 1983 - 1997 + (3) 1998 - 2001 +	sd log(n) set to 1	yes
Trial run 1	InterCatch 2002 - 2019, reconstructed catch time series	InterCatch, raised discards; reconstructed Dutch landings for time period 1984-1997 by applying average Dutch landings proportion 1974 - 1983 (0.64)	1983 - 2020	1985 - 2019		Different uncertainties were applied on catch for different time periods: + (4) 1983 - 1997 + (3) 1998 - 2001 +	sd log(n) set to 1	yes
Trial run 1a	InterCatch 2002 - 2019, reconstructed catch time series	InterCatch, raised discards; reconstructed Dutch landings for time period 1984-1997 by applying average Dutch landings proportion 1974 - 1983 (0.64)	1983 - 2020	1986 - 2019		Different uncertainties were applied on catch for different time periods: + (4) 1983 - 1997 + (3) 1998 - 2001 +	sd log(n) set to 1	yes
Trial run 4	InterCatch 2002 - 2019, reconstructed catch time series	InterCatch, raised discards; reconstructed Dutch landings for time period 1984-1997 by applying average Dutch landings proportion 1974 - 1983 (0.64)	1983 - 2020	2002 - 2019	2002 - 2019	Different uncertainties were applied on catch for different time periods: + (4) 1983 - 1997 + (3) 1998 - 2001 +	sd log(n) set to 1	yes

SPiCT trial run 1 (trying longer index time-series of combined Q3 index: 1985–2019)

A longer time-series for the combined third quarter biomass index was used for this trial run (Figure 11.10 lower panel). The results are same to that of the previous SPiCT assessment, but the uncertainties around the relative F seems to increase (Figure 11.11). The diagnostics show issues for both indices with autocorrelation and for the IBTSQ1 also for the normality plot (Figure 11.12). There are strong patterns in the retro plots and high uncertainties (Figure 11.13). The first value of the combined Q3 index (1985) is very large and might be biased. However, in another trial run (trial run 1a) this value was excluded from the analysis but the results did not change (figures not shown here).

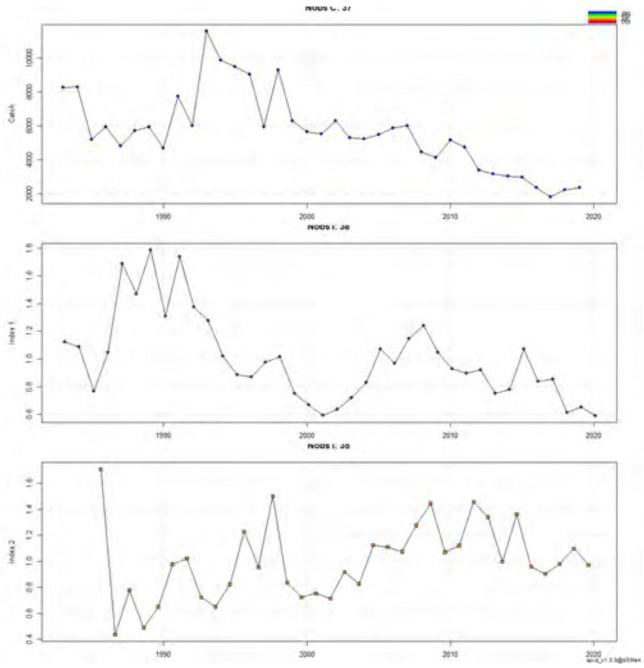

Figure 11.10. Flounder Subarea 4 and Division 3.a: SPiCT trial run 1 input data.

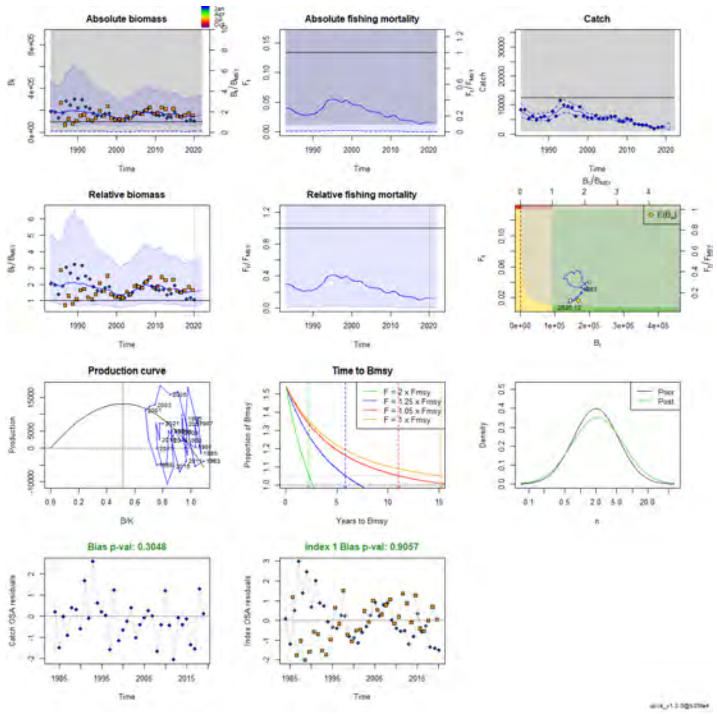

Figure 11.11. Flounder Subarea 4 and Division 3.a: SPiCT trial run 1 results.

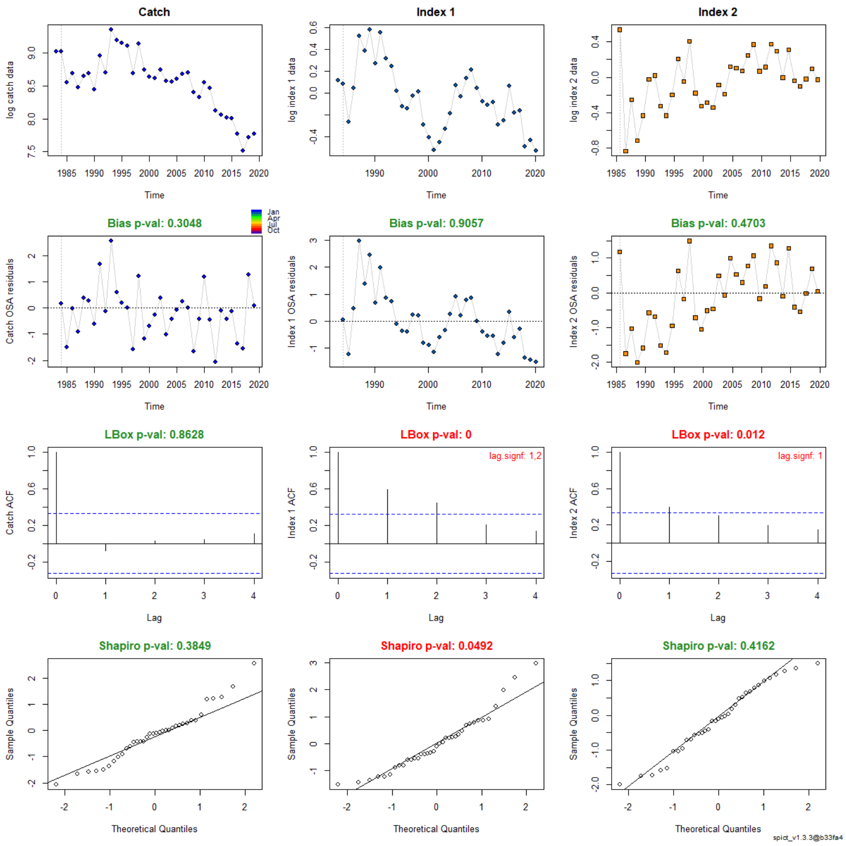

Figure 11.12. Flounder Subarea 4 and Division 3.a: Diagnostics of SPiCT trial run 1.

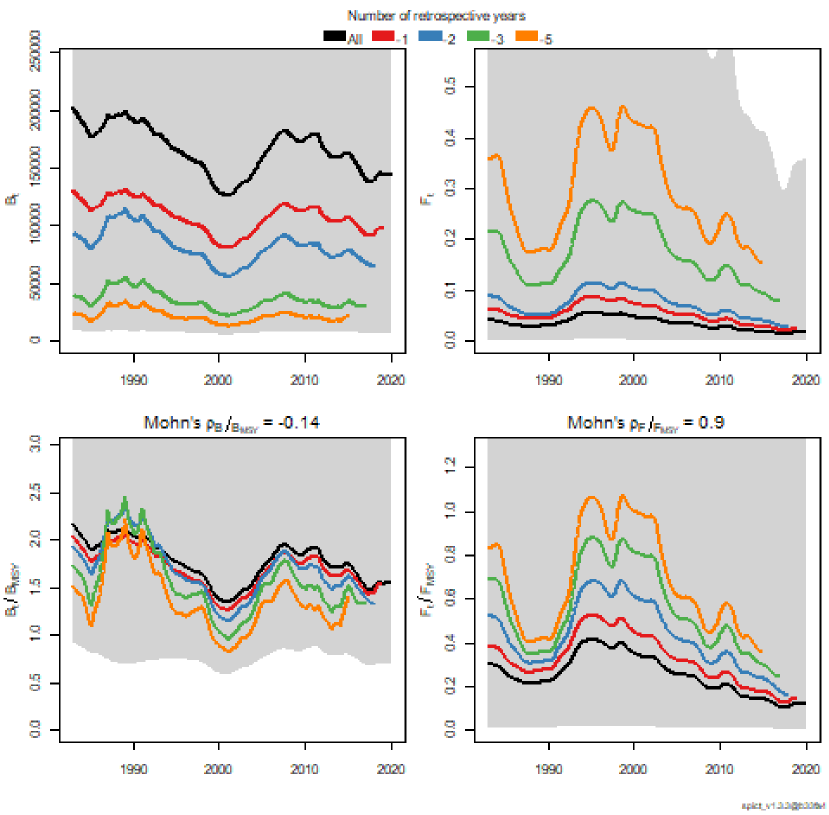

Figure 11.13. Flounder Subarea 4 and Division 3.a: Retrospective analyses for SPiCT trial run 1.

SPiCT trial run 4 (including DYFS index into assessment)

Including the DYFS biomass index into the assessment did not change the results compared to the previous SPiCT assessment. The diagnostics are o.k. but the uncertainties around the relative biomass and fishing mortality are still very high.

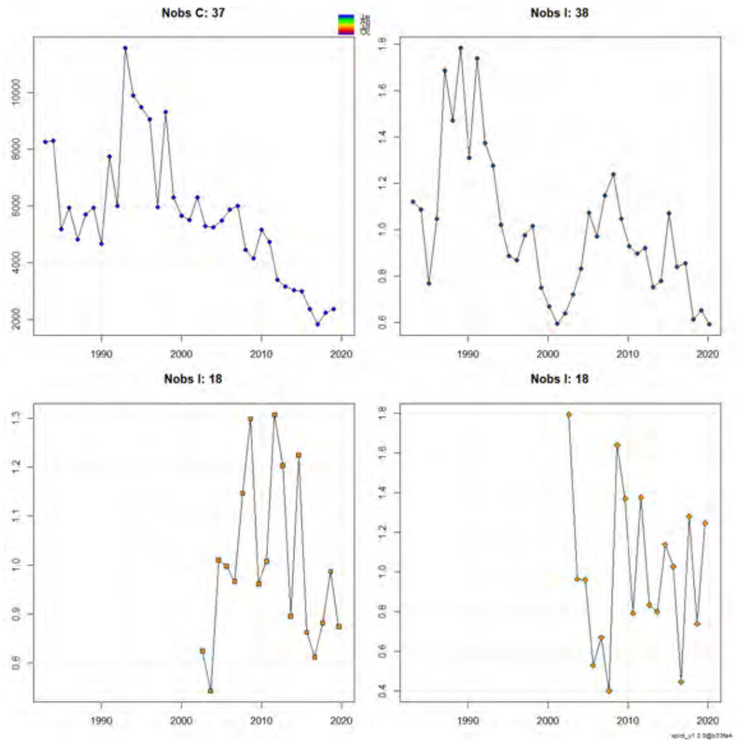

Figure 11.14. Flounder Subarea 4 and Division 3.a: SPiCT trial run 4 input data.

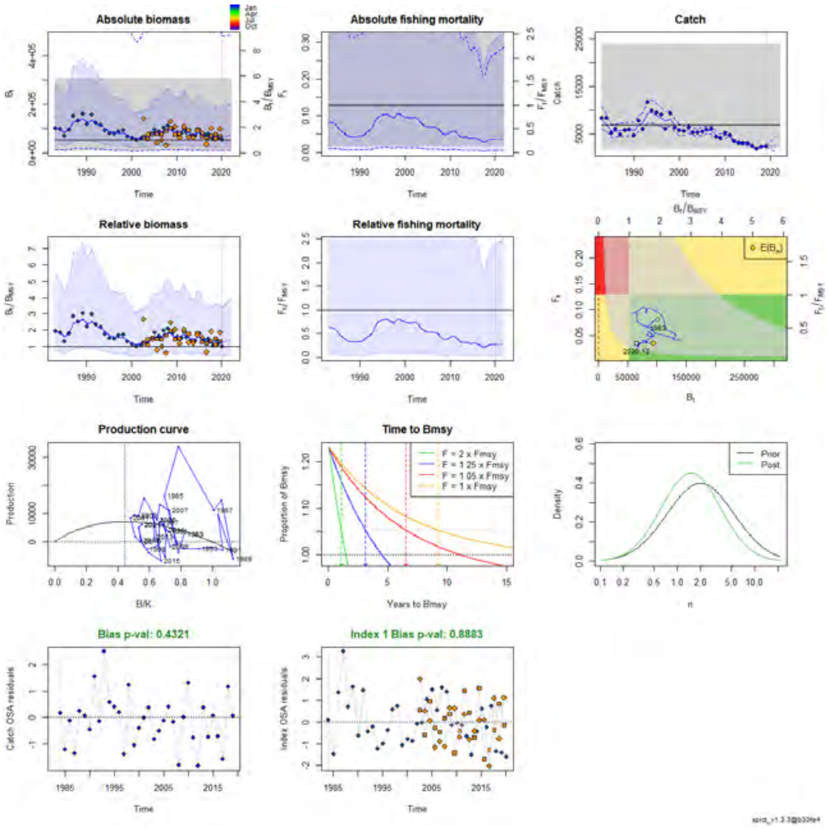

Figure 11.15. Flounder Subarea 4 and Division 3.a: SPiCT trial run 4 results.

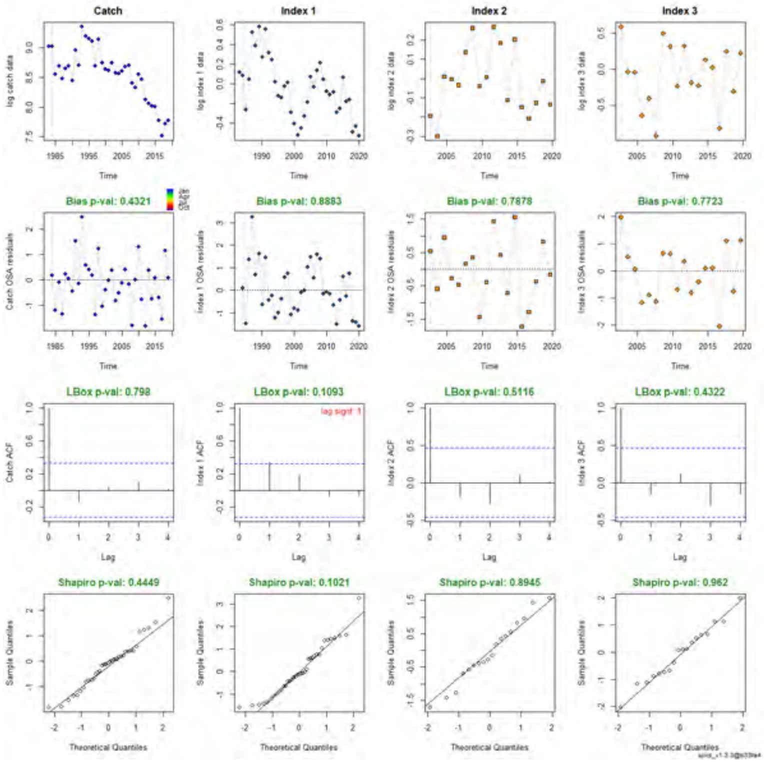

Figure 11.16. Flounder Subarea 4 and Division 3.a: Diagnostics of SPiCT trial run 4.

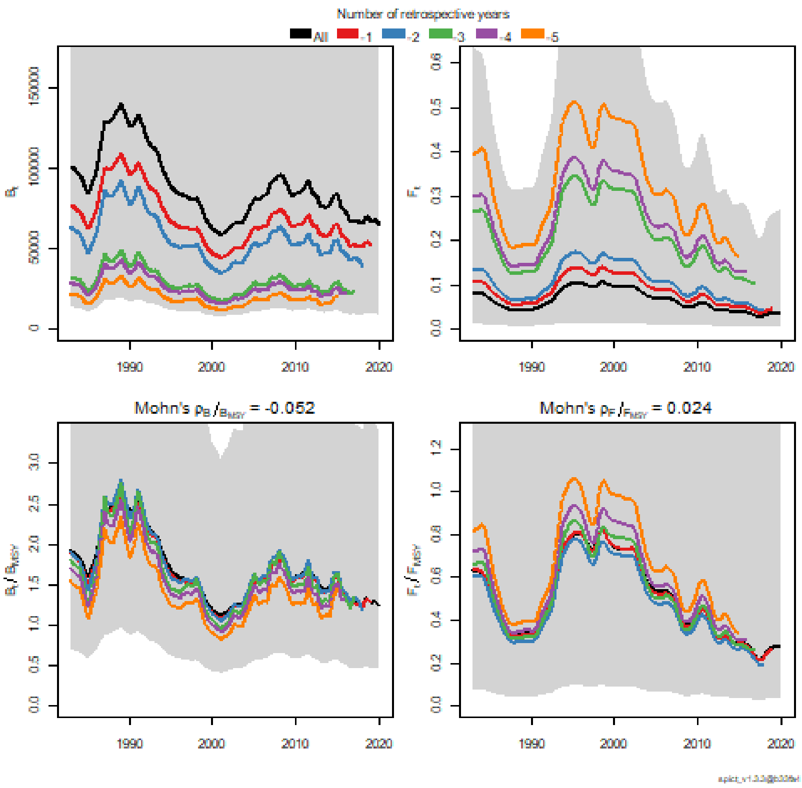

Figure 11.17. Flounder Subarea 4 and Division 3.a: Retrospective analyses for SPiCT trial run 4.

11.4 Future considerations/recommendations

Further exploration of prior settings and sensitivity analyses are still to be done.

11.5 Reviewers report

Reviewers report is only provided for the stocks that were considered for the assessment benchmark meeting (15–19 February 2021).

11.6 References

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ICES. 2013b. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES CM 2013/ACOM:13.

ICES. 2018a. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA 2018). 5–9 February, ICES HQ Copenhagen, Denmark. ICES CM 2018/ACOM:33.

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Pedersen, M. W., Berg C. W. 2017. A stochastic surplus production model in continuous time. Fish and Fisheries, 18: 226–243. DOI: 10.1111/faf.12174.

12 Dab *(Limanda limanda*) in Subarea 4 and Division 3.a (dab.27.3a4)

12.1 Introduction

Dab is a widespread demersal flatfish species on the Northeast Atlantic shelf and distributed from the Bay of Biscay to Iceland and Norway, including the Barents Sea and the Baltic. In the North Sea it is one of the most abundant species distributed over the whole area in depths down to 100 m. The main concentration of dab is located in the southeastern North Sea especially that of the younger age groups 1–2. Older age groups are more distributed towards the central and more Northern parts of the North Sea (Figure 12.1). Generally, dab abundance decreases towards the northern parts of the North Sea. Dab feeds on a variety of small invertebrates, mainly polychaete worms, shellfish and crustaceans. Early sexual maturation was reported for dab, maturing at ages of 2 to 3 years corresponding to approximately 11 cm to 14 cm total length. Peak spawning in the southeastern North Sea occurs from February to April. Several spawning grounds and the wide distribution of dab indicate the presence of more than one stock. Meristic data (Lozán, 1988) corroborate the hypothesis of several stocks for dab, distinguishing significantly between populations from western British waters, the North Sea and the Baltic Sea.

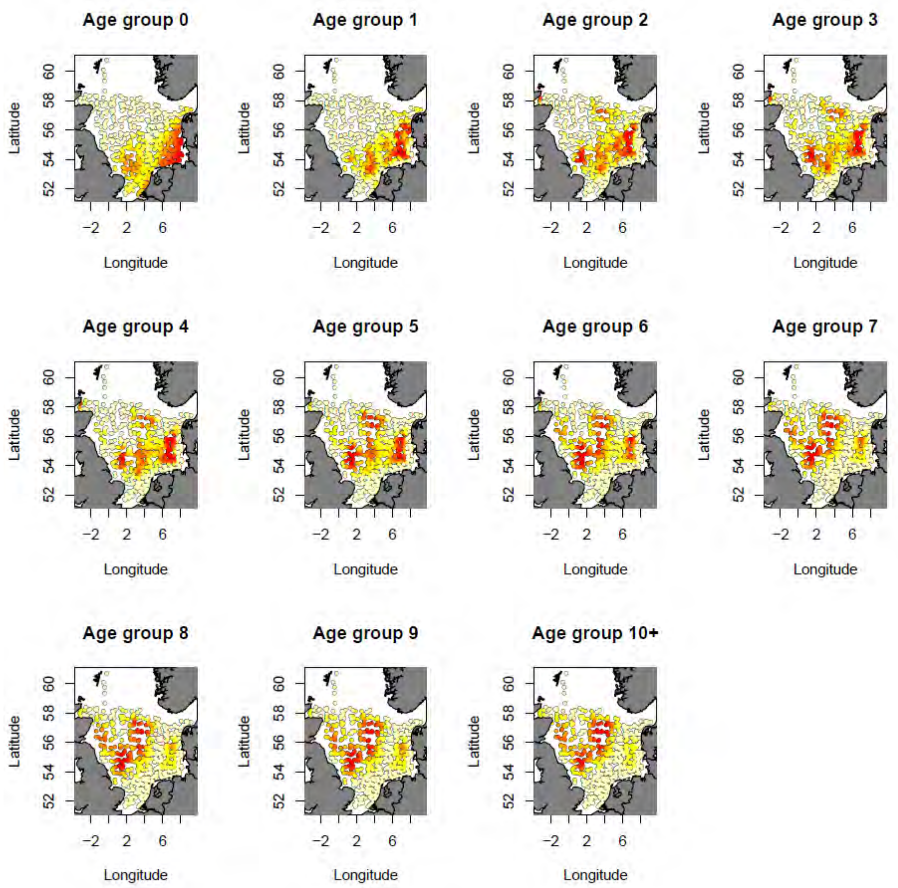

Figure 12.1. Dab distribution in the North Sea by age group obtained by the Beam Trawl Surveys.

The species is of limited commercial value and there is no directed target fishery for dab. Dab is mainly a bycatch species in the mixed fisheries for plaice and sole and discard rates can be extremely high (~90%). The North Sea Dab stock was assessed for the first time by the Working Group on Assessment of New MoU Species (ICES, 2013a). Because only official landings and survey data were available at that time, dab was defined as a category 3 species according to the ICES guidelines for data-limited stocks (ICES, 2012). Since 2014, it is regularly assessed by the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, WGNSSK 2014). Since 2015, dab was included in the official ICES data call for the WGNSSK and discard estimates could be included into the dab assessment since then. In 2016, a benchmark assessment was conducted for this stock. For this benchmark assessment, catch data from 2002 were requested and uploaded into the InterCatch data portal by all relevant countries (ICES, 2016). The benchmark agreed on the use of a survey-based assessment model (SURBAR; Needle, 2015) to inform stock status of North Sea dab (ICES, 2016). This model provides relative estimates of the spawning stock, recruitment, and total mortality. During the WGNSSK 2017 MSY proxy reference points were determined applying the Surplus Production Model in Continuous Time (SPiCT, Pedersen and Berg, 2017) and catch advice for dab was provided for 2017 and 2018. In 2017, the combined TAC for dab and flounder was removed (EU COM, 2017/595). North Sea dab has become a non-target species with no TAC since then, and ICES has not been requested to provide advice on fishing opportunities for this stock since then. Still, triennial advice is requested for this stock to evaluate the stock status and exploitation status. For this purpose, the SPiCT model is used. However, the SPiCT model for dab has never gone through a benchmark assessment.

During the previous data collection and evaluation workshop of the WKMYSPiCT benchmark some issues were identified for the dab SPiCT assessment model. Table 1 displays the input data and settings of the current dab SPiCT model used by the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, 2020). During the previous data collection and evaluation meeting of the WKMYSPiCT benchmark workshop some points were addressed which should be further investigated:

a) investigate extending the delta-GAM index with Belgian BTS data (2010–2020) and German BTS data (prior to 2002);
b) investigate the inclusion of additional survey information, e.g. IBTS Q1 and IBTS Q3, Sole Net Survey (SNS);
c) investigate the inclusion of reconstructed historic catch data (before 2002);
d) investigate the use of priors and do sensitivity analysis (*to be done*).

12.2 Input data for stock assessment (ToR 1 & 2)

Survey indices

So far, only Beam Trawl Survey (BTS) data were used as survey input data for the current dab SPiCT model. Data of both Dutch surveys, the BTS Isis and BTS Tridens, were used separately for the period 1987–2002 and 1996–2002 respectively. The period 2003–2019 was covered by an age-based, combined BTS survey index including the Dutch survey data and German survey data. However, during recent years more survey data became available (Table 2), especially the Belgian BTS (2010–2020) and German BTS data (previous to 2002) were uploaded into the ICES DATRAS database.

In a first step, the length distributions from commercial catches (InterCatch data 2014–2019) and from survey data were compared (Figure 12.2). The commercial length distribution displays two modes, with the left one containing 0-group and 1-group dab. The right mode is very similar to the length distribution from the survey data. Thus, it was concluded that the survey data represent the exploitable biomass of the stock.

The NS-IBTS data were used to construct biomass indices for the 1st and 3rd quarter (Figure 2). Both indices show similar trends, with an overall increasing biomass until 2016 and sharp decrease afterwards. Four different beam trawl surveys (BTS, all 3rd quarter) were compared (Figure 3, left panel). The longest available time-series is the NL-BTS with data from 1985 onwards. Since the mid-1990s the trends of the NL-BTS and the DE-BTS are comparable to the IBTS index trends while the BE-BTS index fluctuates with no clear trend. High index values were also observed in the early part of the NL-BTS. However, it has to be noted here that in these earlier years the area coverage was limited to the south-eastern North Sea, the main distribution area of dab (see figures in Annex 5). The Sole Net Survey (SNS) index trend is also similar to the NL-BTS and DE-BTS but shows very high interannual fluctuations compared to the other index time-series. Therefore, these data were not included in further analyses. A combined BTS 3rd quarter index was modelled taking a gear effect into account (Figure 3, right panel). High uncertainties occur for the earlier years of this index. As mentioned above, in these years the survey area was restricted to the southeastern part of the North Sea. Hence, for these years (1985–1995) a separate index was calculated and a combined BTS 3rd quarter index for the years 1996–2020.

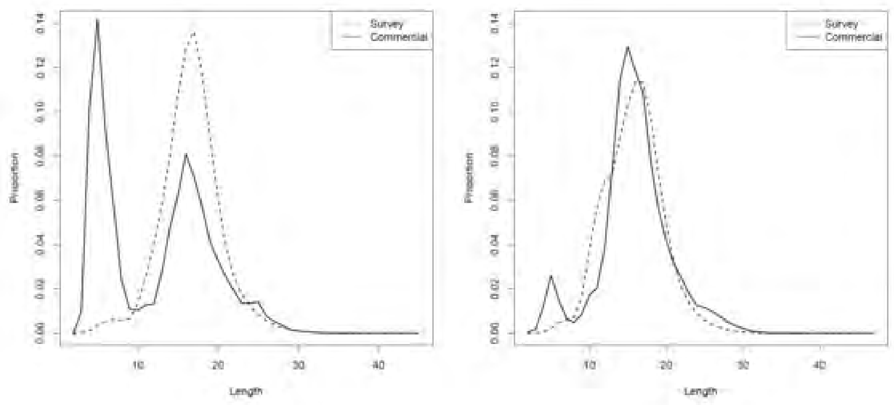

Figure 12.2. Dab (*Limanda limanda*). Comparison between length distributions obtained by commercial catches and survey data in the North Sea. Left panel IBTS Q1 survey and commercial Q1 data, right panel IBTS Q3 and BTS Q3 survey data. Length in cm.

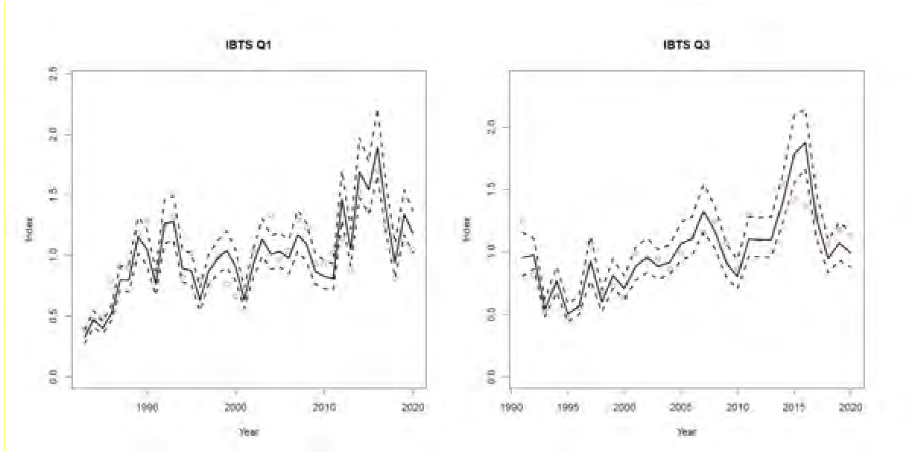

Figure 12.3. Dab (*Limanda limanda*). Standardized NS-IBTS Q1 biomass index (left panel) and NS-IBTS Q3 index (right panel). Red dots display stratified mean indices over ICES rectangles. The black lines display GAM modelled indices with uncertainties (dashed black line).

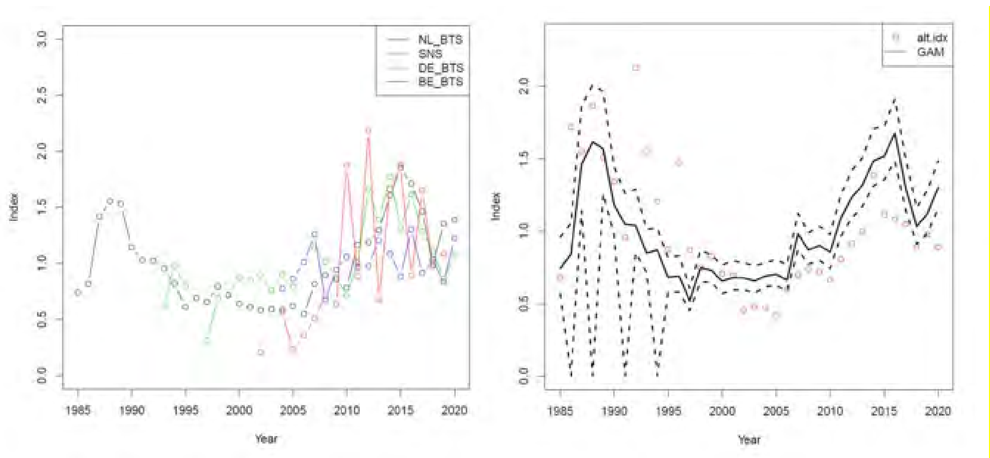

Figure 12.4. Comparison between the different Beam Trawl Survey indices (NL, DE, BE) and the Sole Net Survey (SNS) index (left panel) and a combined Beam Trawl Survey index (NL, DE, BE). Red dots in the right panel display stratified mean indices over ICES rectangles and the black lines display GAM modelled indices with uncertainties (dashed black line).

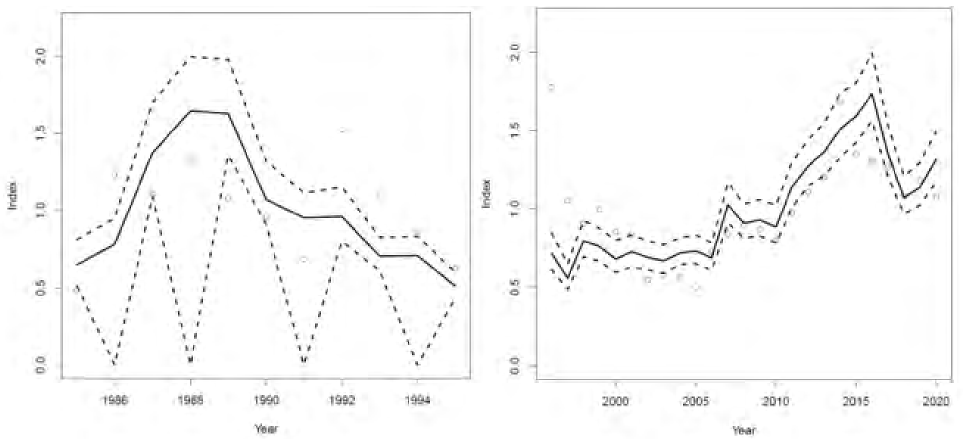

Figure 12.5. GAM modelled BTS 1985–1995 (left panel), BTS combined 1996–2020 (right panel) indices. Red dots display stratified mean indices over ICES rectangles. The black lines display GAM modelled indices with uncertainties (dashed black line).

Landings and catch data (point c)

Data on dab discards and hence estimates on total catch are available for the time period 2002–2019. Prior to 2002 only official landings data are available. Because dab is a low value species with very high discard rates, the landings data alone are not indicative of the total catch. Further, for some years Dutch dab landings were not reported (years with missing data 1984–1987, 1990–1997). This is not negligible because usually the largest proportion of dab landings is reported for the Dutch fleets. Therefore, the mean Dutch landings (3326 t) were added to the official landings for those years. Then, in order to include catch data prior to 2002 into the SPiCT model, discards were reconstructed by up-scaling the official landings by the mean discard fraction from the total catch obtained from InterCatch data (Figure 5). On average 84% of the total catch were estimated discards (Table 2). The reconstructed catch time-series was then used for trial SPiCT runs. The best results were obtained by using a truncated catch time-series matching the period of available survey data (1983–2019; trial runs 4 to 6).

Table 12.1. Dab landings, discards and total catch obtained from InterCatch data (ICES WGNSSK, 2020).

Year	Landings	Imported Discards	Raised Discards	Total Discards	Total Catch	% Discards
2002	8588	14448	12183	26631	35219	76%
2003	9433	22152	22778	44930	54363	83%
2004	8647	18559	15714	34273	42920	80%
2005	9537	21295	13996	35291	44828	79%
2006	10236	16106	21871	37977	48214	79%
2007	9881	8936	24392	33328	43208	77%
2008	8645	14781	12598	27379	36024	76%
2009	7040	20652	12769	33421	40461	83%
2010	8279	23688	18798	42486	50765	84%
2011	7422	28227	16234	44460	51882	86%
2012	7047	33220	19412	52632	59679	88%
2013	6611	36855	16621	53476	60087	89%
2014	5047	35383	18350	53733	58780	91%
2015	5082	26468	20904	47372	52454	90%
2016	5085	29023	15788	44811	49896	90%
2017	3598	22241	9274	31515	35113	90%
2018	4233	28630	11915	40545	44792	91%
2019	5024	26330	9372	35702	40725	88%

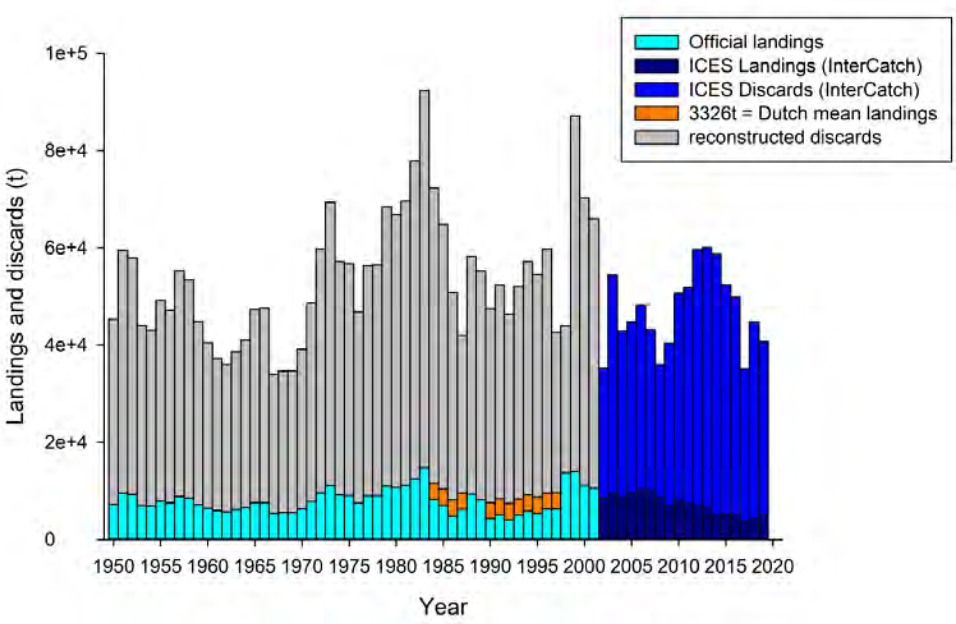

Figure 12.6. Dab catch time-series in landings and discards.

12.3 Stock assessment (ToR 3)

Output and diagnostics of the current dab SPiCt model.

The detailed code, outputs and diagnostics can be found in Annex 2 of the working document (WD -North Sea Dab (dab.27.3a4, *Limanda limanda*) SPiCT Assessment model; WKMYSPICT data collection and evaluation work shop). The results of the SPiCT assessment for dab in Subarea 4 and Division 3.a showed that the relative fishing mortality is below the reference F_{MSY} proxy and the relative biomass is above the reference B_{MSY} * 0.5 proxy. Also, the estimated uncertainty boundaries around the relative F values show that these are below the reference F_{MSY} proxy for recent years, and those estimated for the relative biomass are above the reference B_{MSY}* 0.5. The SPiCT model as used, has never gone through a benchmark assessment.

Table 12.2. Dab in Subarea 4 and Division 3.a. SPiCT settings and input data for the current SPiCT model (WGNSSK, 2020).

Setting/Data	Values/Source
Catch time-series	InterCatch data 2002–2019
BTS Isis	1987–2002, >12 cm
BTS Tridens	1996–2002, >12 cm
Combined BTS (Isis, Tridens, Solea)	2003–2019, Age > 1 yr
SPiCT settings	Default settings used from stockassessment.org; inp$phases$logn <- -1

12.3.1 Exploratory assessments

	Catch data	Reconstruction of catch	IBTS Q1 Biomass Index	IBTS Q3 Biomass Index	BTS Q3 Biomass indices	BTS indices	uncertainties	priors	converged
Base run from current SPiCT	2002 - 2019	InterCatch, raised discards				BTS Isis 1987-2002, >12cm; BTS Tridens 1996-2002, >12cm;Combined BTS (NL, DE; Age >1yr)		inp$phases$logn <- -1	yes
Trial run 1	2002 - 2019	InterCatch, raised discards	1983 - 2019	1991 - 2019	BTS 1985 - 1995; BTS		around indices	inp$phases$logn <- -1	yes
Trial run 2	1950 - 2019	official landings only	1983 - 2019	1991 - 2019	BTS 1985 - 1995; BTS		around indices	inp$phases$logn <- -1	yes
Trial run 3	1950 - 2019	reconstructed catches 1950 - 2001; InterCatch	1983 - 2019	1991 - 2019	BTS 1985 - 1995; BTS 1996 - 2019		around indices	inp$phases$logn <- -1	yes
Trial run 4	1983 - 2019	reconstructed catches 1983 - 2001; InterCatch	1983 - 2019	1991 - 2019	BTS 1985 - 1995; BTS 1996 - 2019		around indices	inp$phases$logn <- -1	yes
Trial run 5	1983 - 2019	reconstructed catches 1983 - 2001; InterCatch 2002 - 2019	1983 - 2019	1991 - 2019	BTS 1985 - 1995; BTS 1996 - 2019		around indices; different uncertainties added to catch data	inp$phases$logn <- -1	yes
Trial run 6	1983 - 2019	reconstructed catches 1983 - 2001; InterCatch 2002 - 2019	1983 - 2019	1991 - 2019	BTS 1996 - 2019		around indices; different uncertainties added to catch data	inp$phases$logn <- -1	yes

SPiCT trial run 1 (all new indices included, otherwise the same as old WGNSSK run)

See script and all results in pdf file dab_trial_1.pdf:

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_1.pdf

The results of the trial run with all new indices included are summarized in the figures below. Compared to the available survey data the catch data time-series is quite short. However, overall the results do not indicate any major problems with the input data. There seem to be some issues with the IBTSQ1 index and with the combined BTSQ3 index (see Index 1 and Index 3 in Figure 5). Figure 6 displays the results of trial run 1. Dab is a not target species with no quota and catch advice is not requested for this stock. Therefore, the relative biomass and relative fishing mortality are sufficient indicators to evaluate the stock status with respect to fishing pressure. The relative biomass is above the reference proxy B/B_{MSY} of 0.5. This was also the case for the results of the previously used SPiCT model. The relative fishing mortality is below the reference proxy F/F_{MSY} of 1. However, in this case the upper uncertainty bound is above the reference. In the previous run the uncertainties bound are much narrower (see WD - North Sea Dab (dab.27.3a4, *Limanda limanda*) SPiCT Assessment model; WKMYSPiCT data collection and evaluation workshop). The retrospective plots show some strange patterns with one peel (-5) completely out of the uncertainty boundaries.

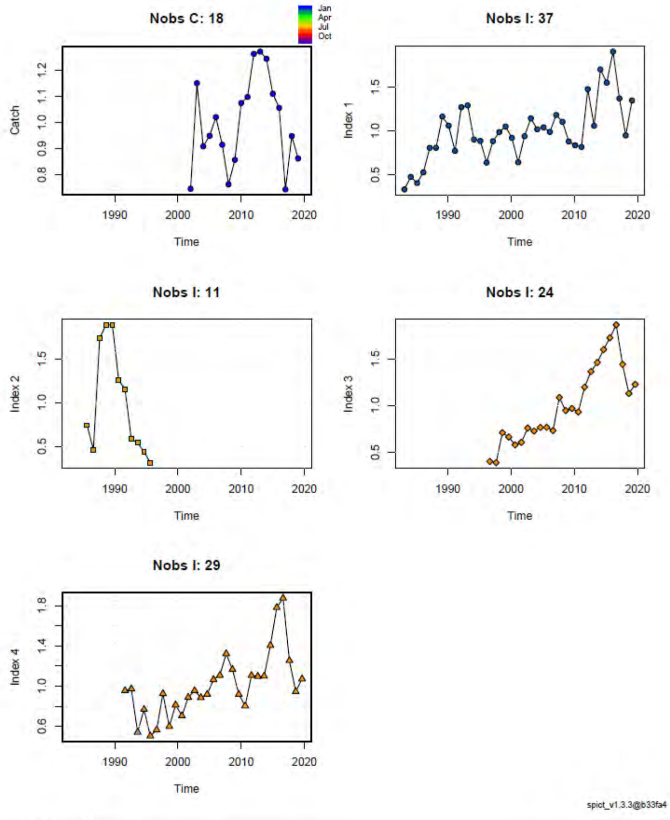

Figure 12.7. Dab (*Limanda limanda*). Input data trial run 1.

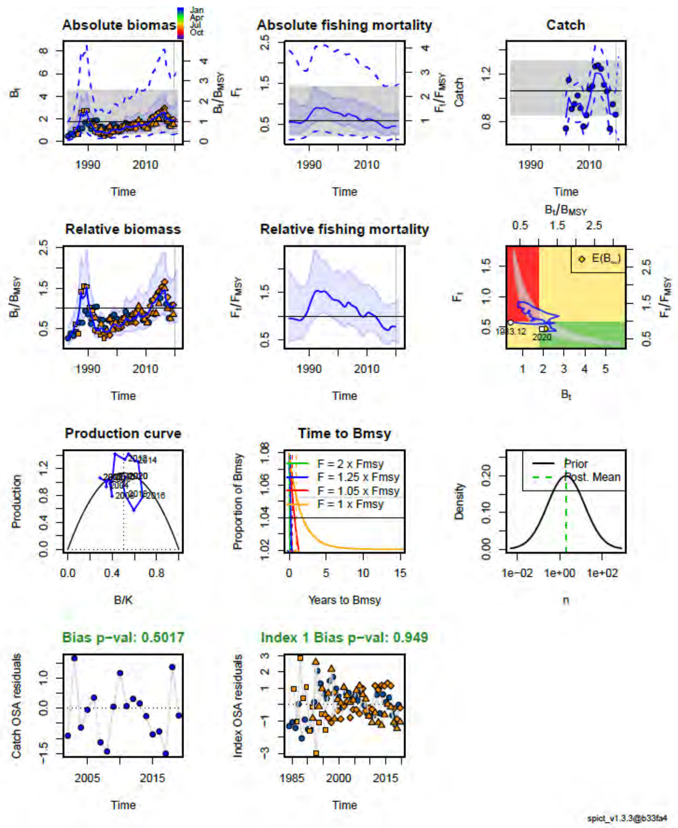

Figure 12.8. Dab (*Limanda limanda*). Results trial run 1.

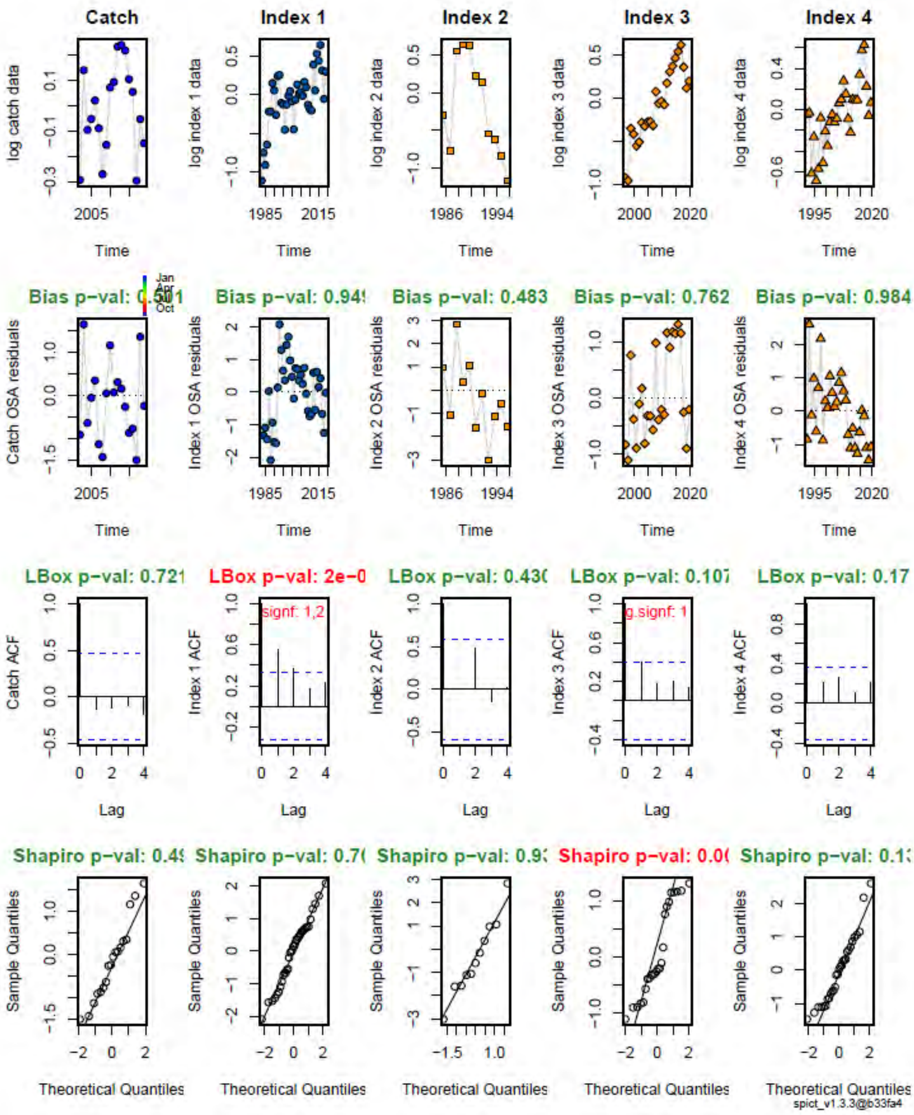

Figure 12.9. Dab (*Limanda limanda*). Diagnostics trial run 1.

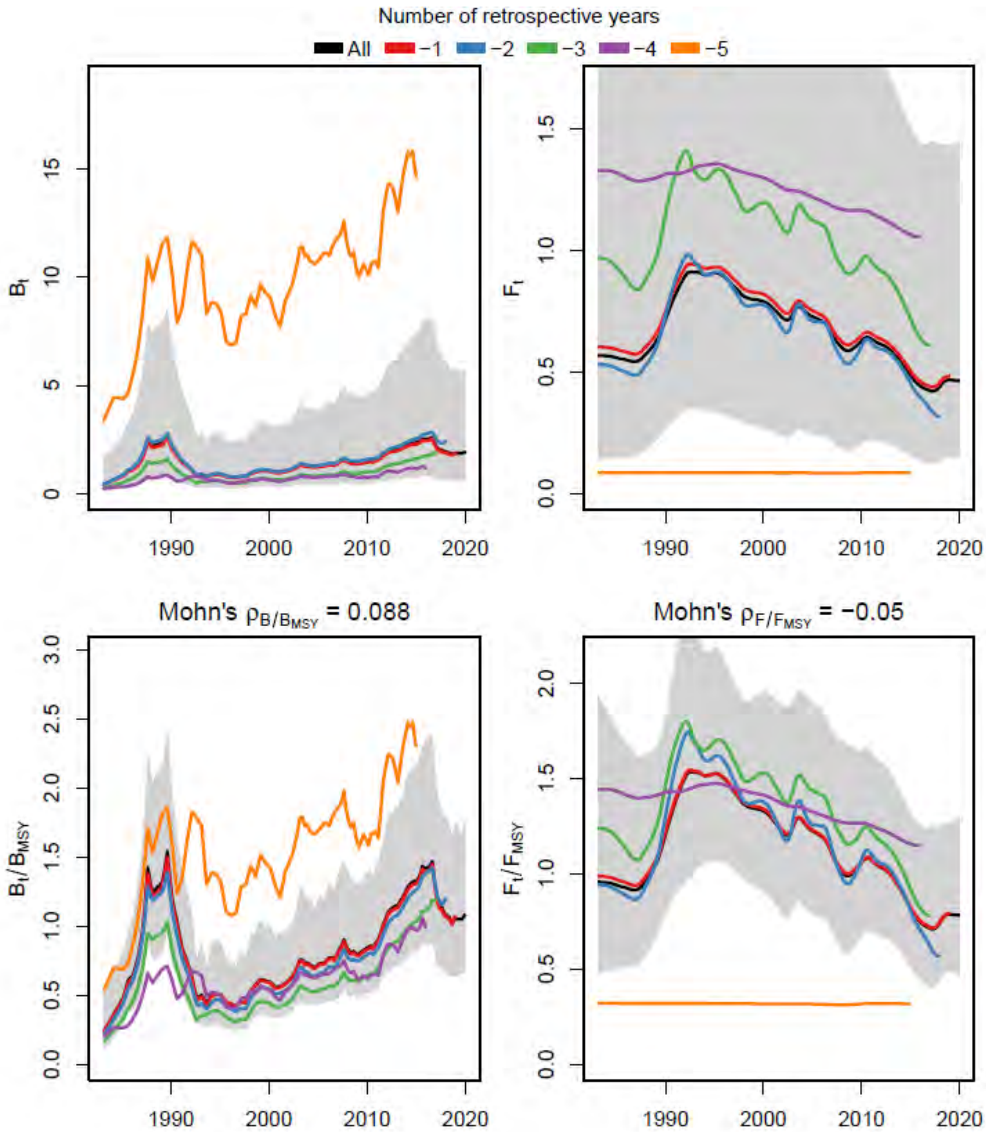

Figure 12.10. Dab (*Limanda limanda*). Retrospective analyses trial run 1.

SPiCT trial run 2 (all new indices included, but using official landings time-series)

See script and results in pdf file dab_trial_2.pdf:

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_2.pdf

In trial 2 all new indices were included. Additionally, the official landings time-series was used as catch input data. However, since dab is a species with high discard rates, landings are probably not indicative of catches. Because the early part of the time-series does not have survey data, there is very high uncertainty around the estimates. Otherwise, the results with respect to relative B/B_{MSY} and F/F_{MSY} are similar to the previous run for the time-series with both, survey and catch data. Retro with very high uncertainties in the early part of the time-series and with similar patterns for the time since 1983.

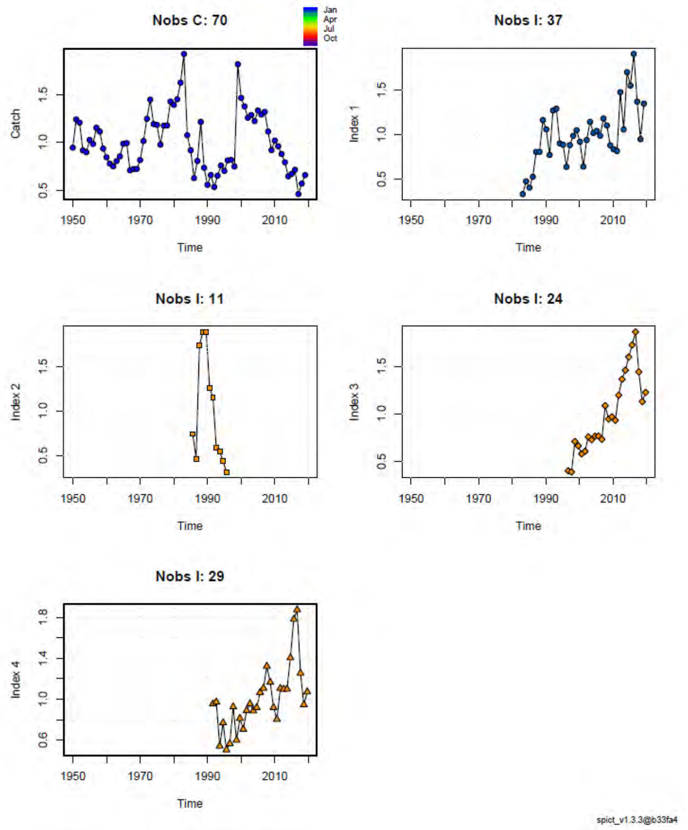

Figure 12.11. Dab (*Limanda limanda*). Input data trial run 2.

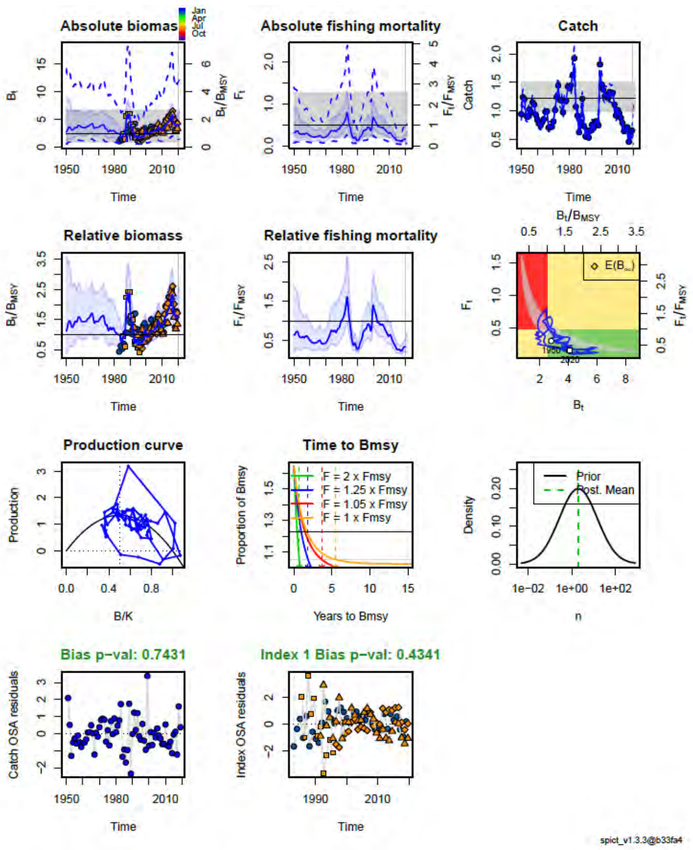

Figure 12.12 Dab (*Limanda limanda*). Results trial run 2.

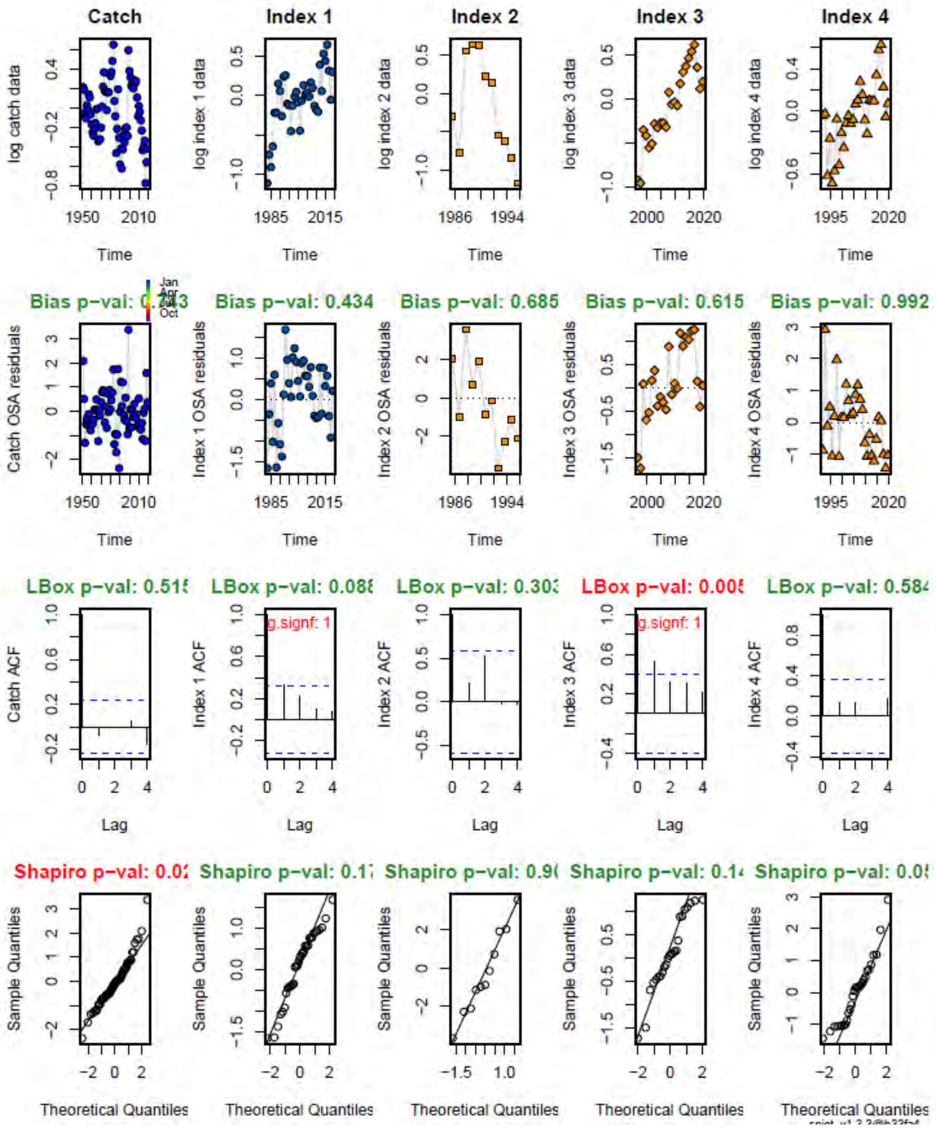

Figure 12.13. Dab (*Limanda limanda*). Diagnostics trial run 2.

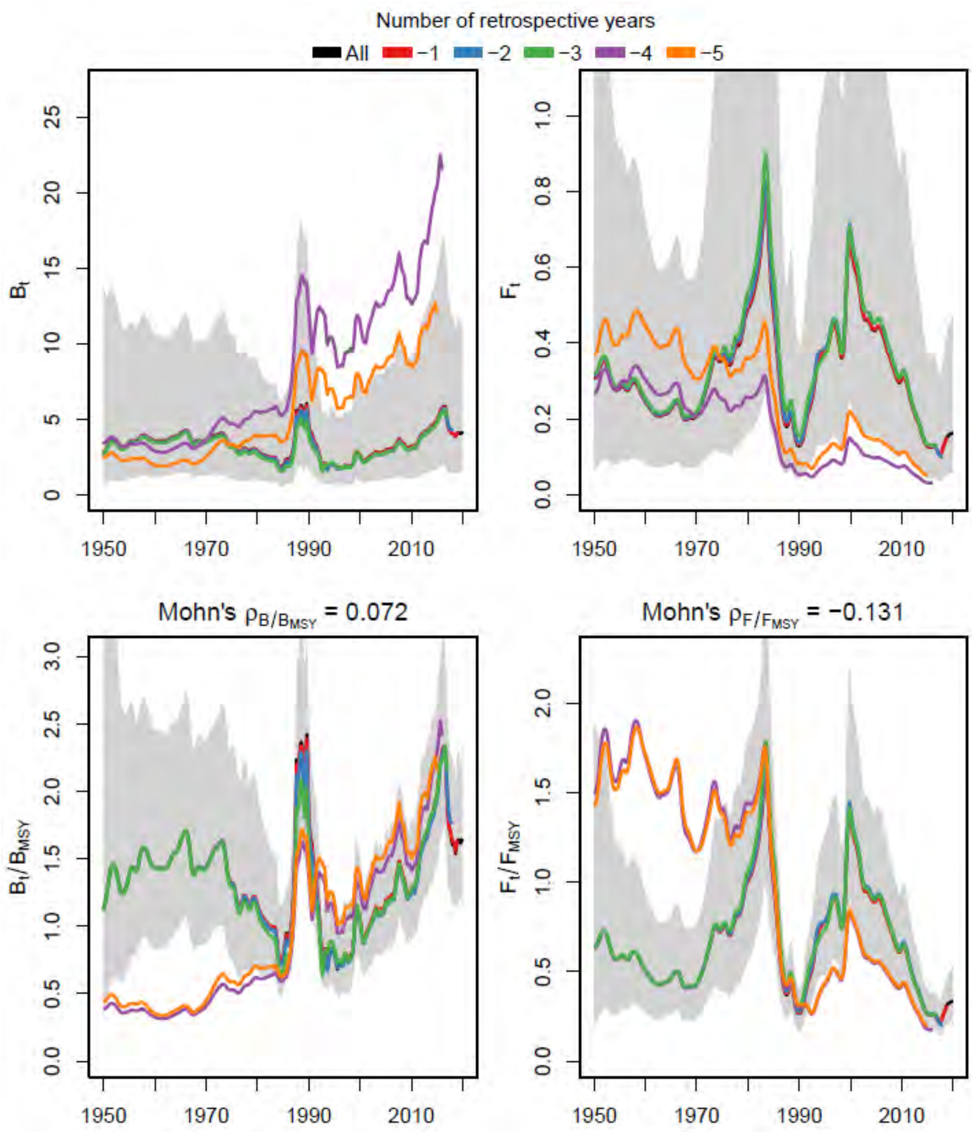

Figure 12.14. Dab (*Limanda limanda*). Retrospective analyses trial run 2.

SPiCT trial run 3 (all new indices included, but official landings up scaled to account for discards)

See script and results in pdf file dab_trial_3.pdf:

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_3.pdf

Same input and settings as trial 2 but landings without catch data were up scaled using the mean discard ratio from InterCatch time-series. In some years, no Dutch landings were reported. For these years the mean Dutch landing (3326 t) was added to the official landings. Again, the results with respect to relative B/BMSY and F/FMSY are similar to the previous runs for the time-series. Retro with very high uncertainties in the early part of the time-series and with similar patterns for the time since 1983.

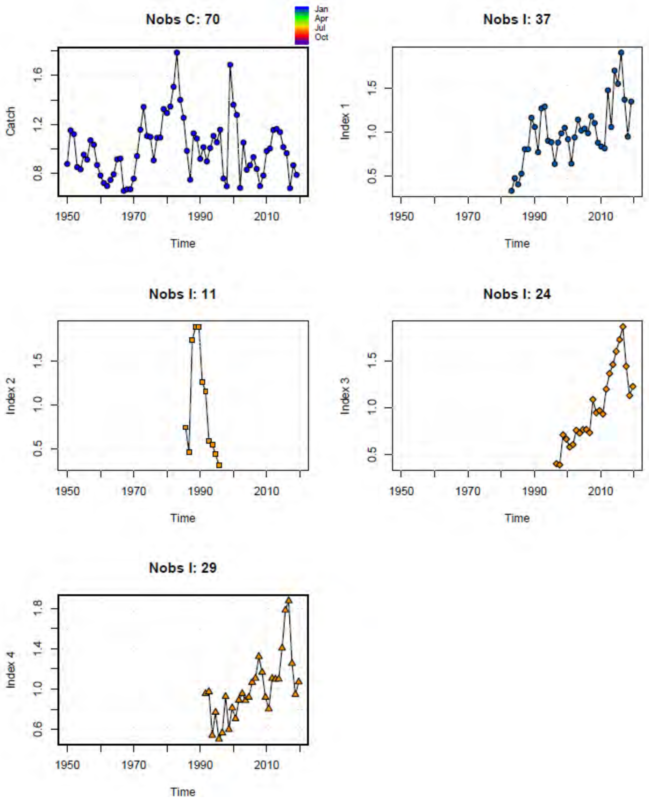

Figure 12.15. Dab (*Limanda limanda*). Input data trial run 3.

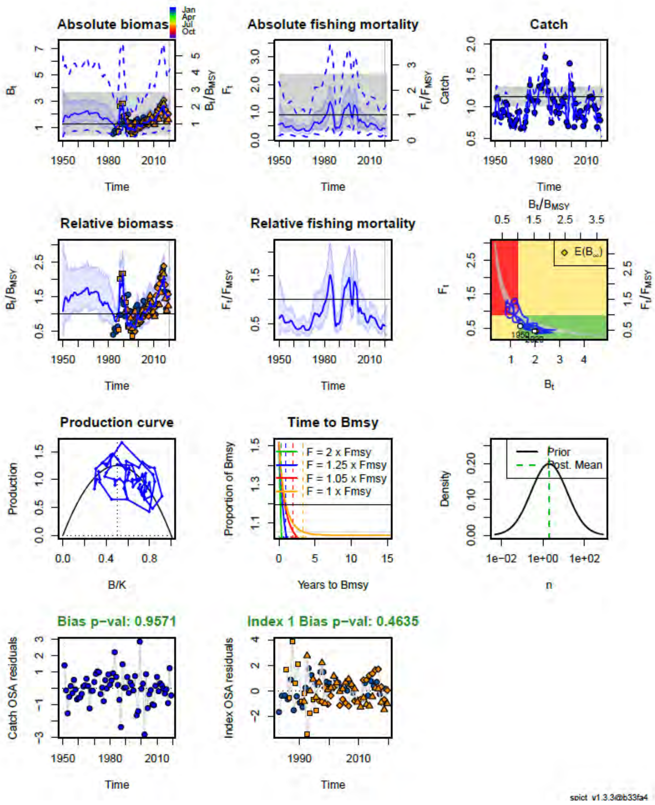

Figure 12.16. Dab (*Limanda limanda*). Results trial run 3.

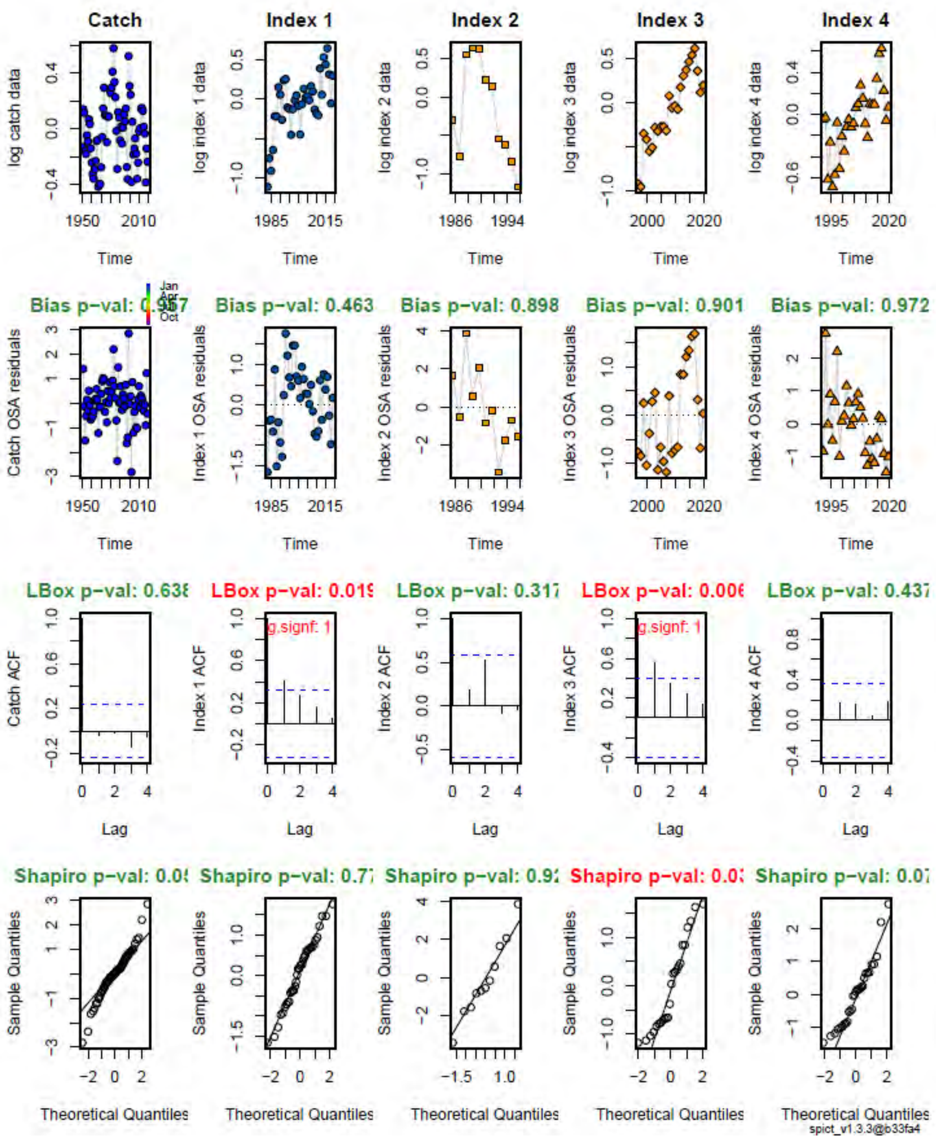

Figure 12.17. Dab (*Limanda limanda*). Diagnostics trial run 3.

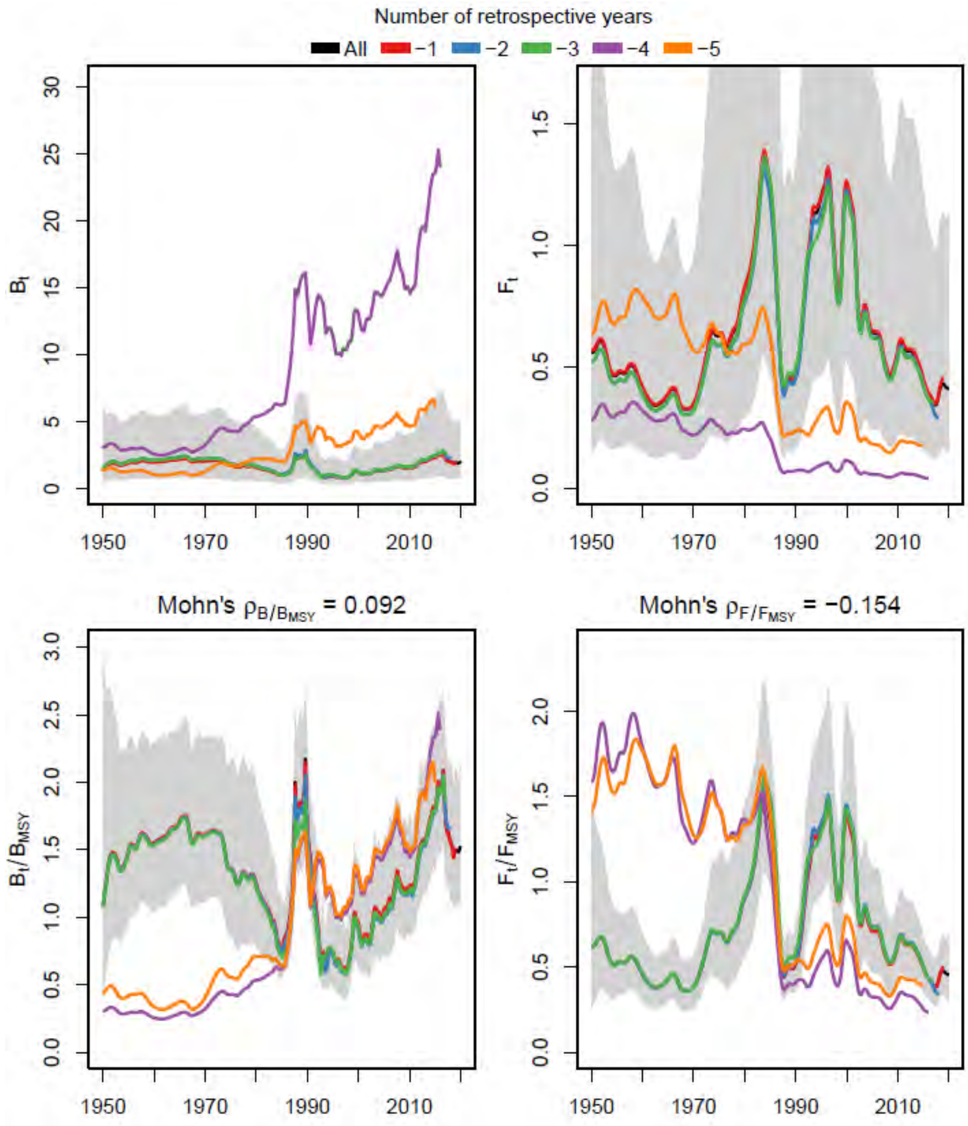

Figure 12.18. Dab (*Limanda limanda*). Retrospective analyses trial run 3.

SPiCT trial run 4 (all new indices included, but official landings up scaled to account for discards; truncated catch time-series >=1983)

See script and results in pdf file dab_trial_4.pdf:

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_4.pdf

Same as trial run 3 but with a truncated catch time-series to match with the start year of available survey data. Similar results with respect to relative B/B_{MSY} and F/F_{MSY} but retro looks better.

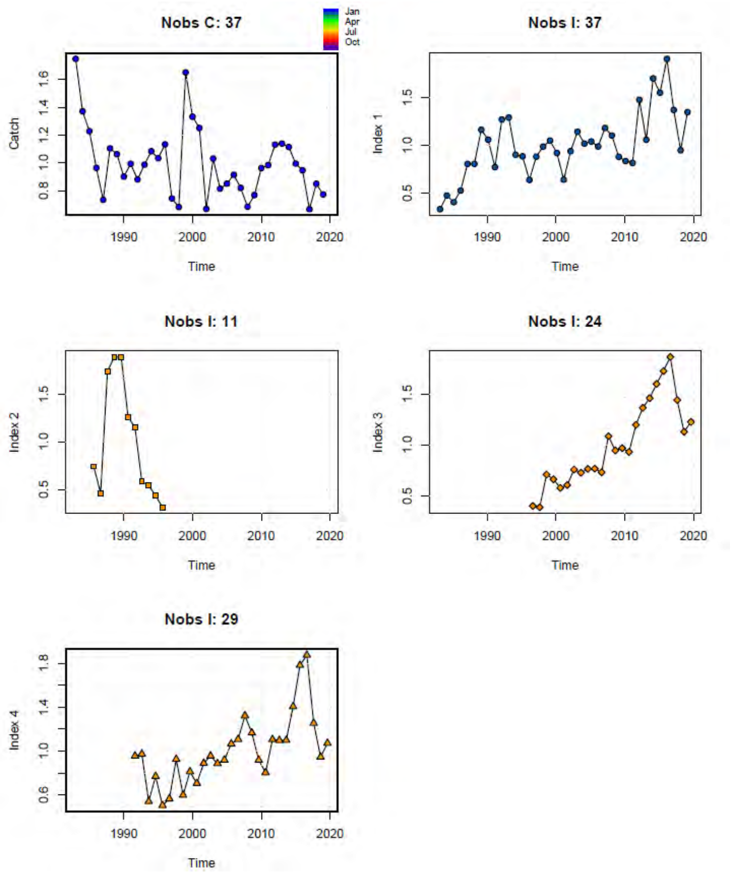

Figure 12.19. Dab (*Limanda limanda*). Input data trial run 4.

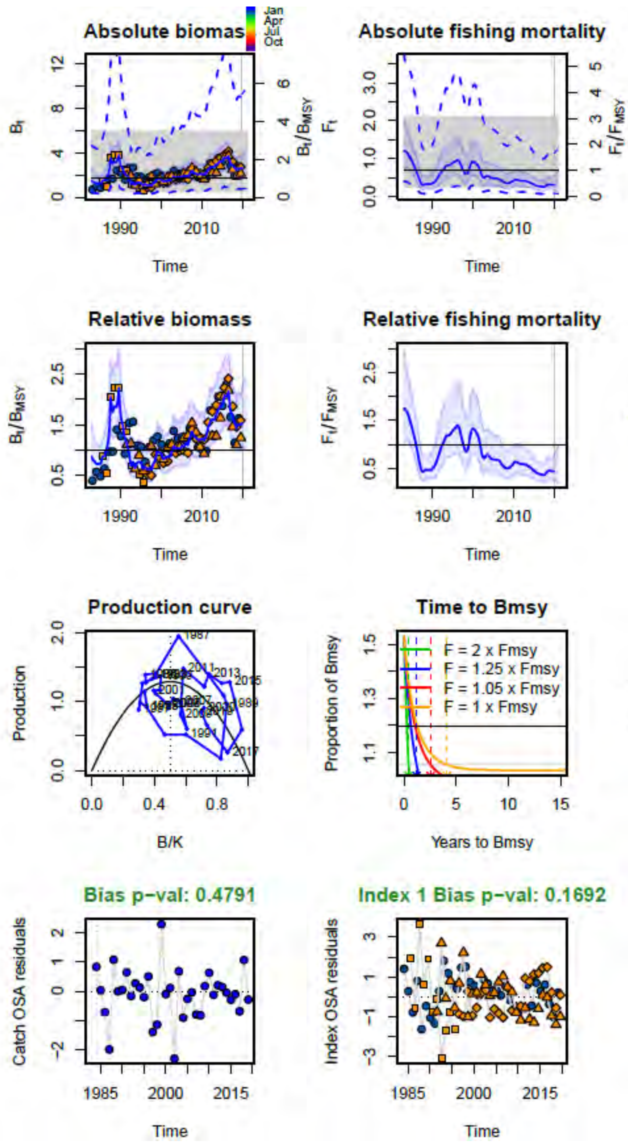

Figure 12.20. Dab (*Limanda limanda*). Results trial run 4.

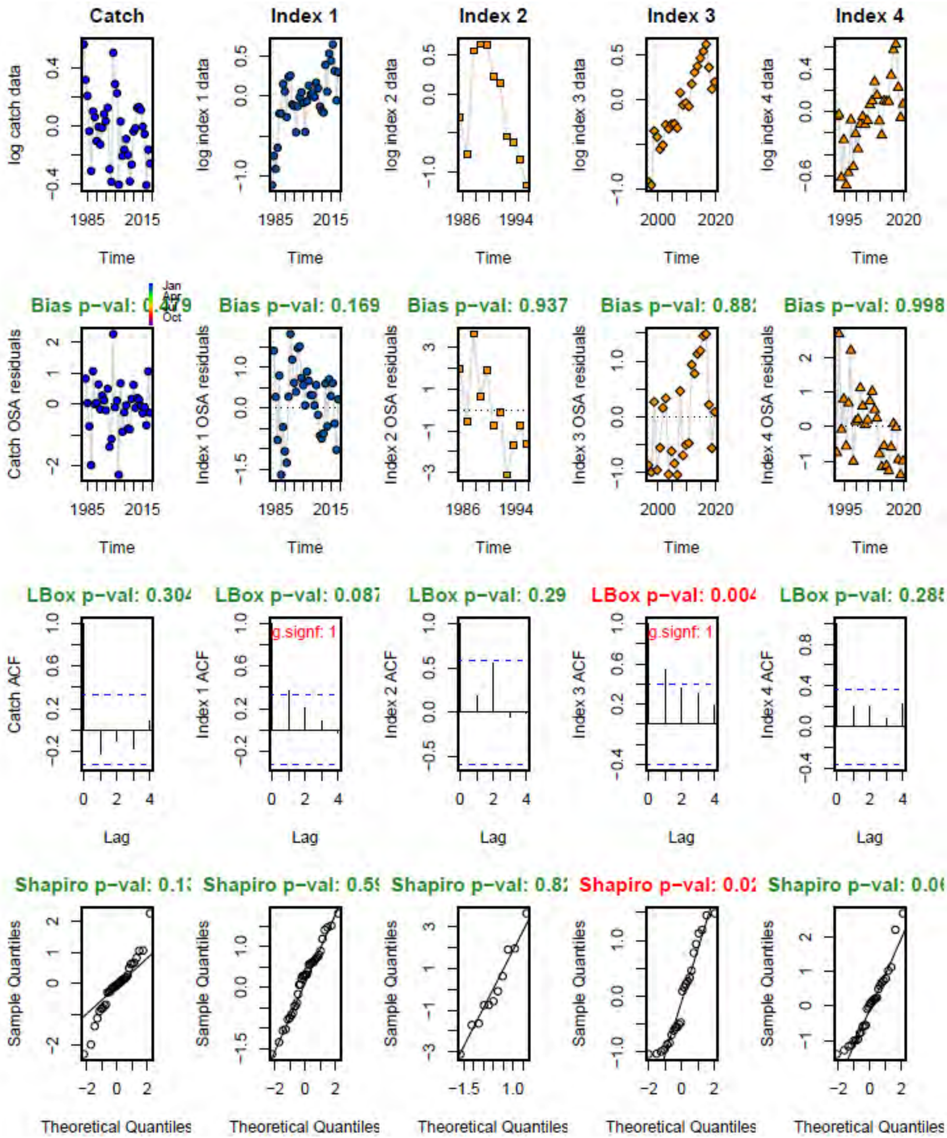

Figure 12.21. Dab (*Limanda limanda*). Diagnostics trial run 4.

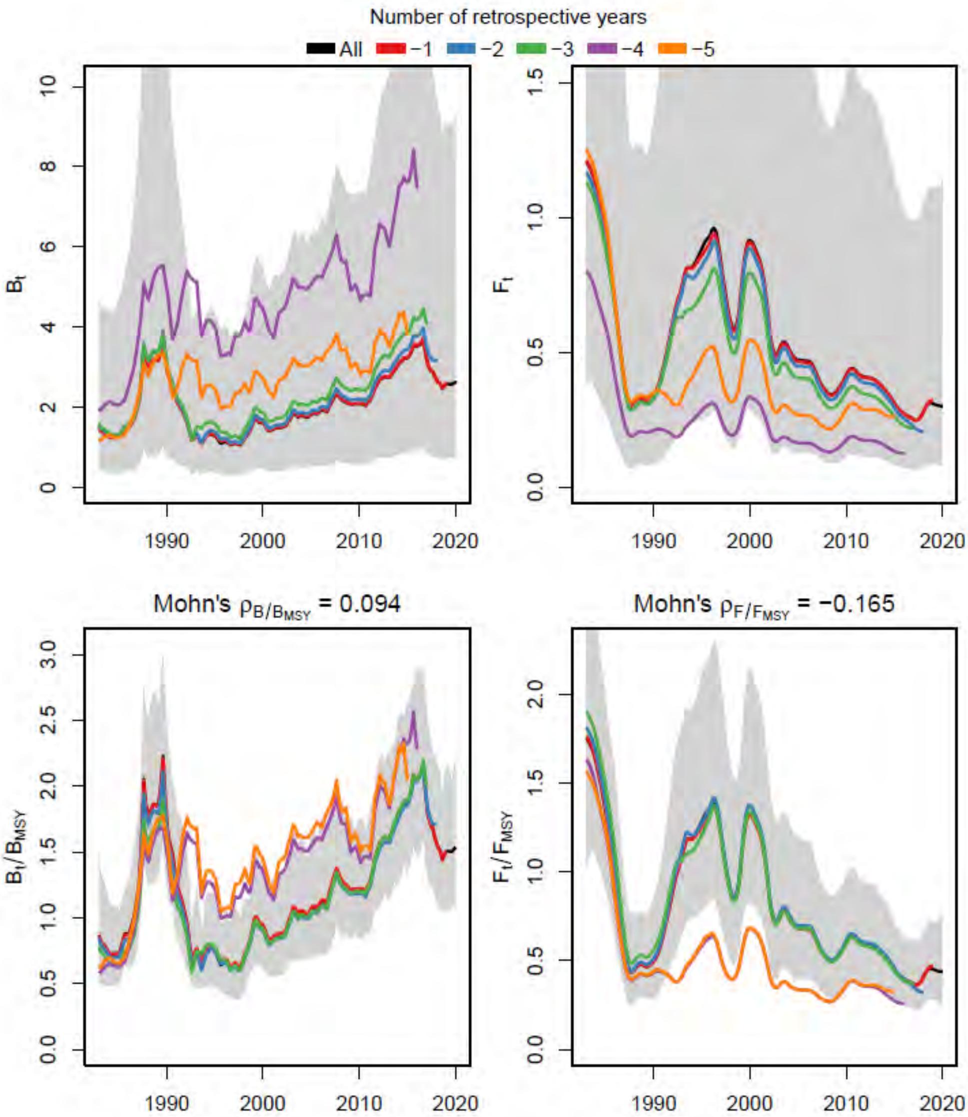

Figure 12.22. Dab (*Limanda limanda*). Retrospective analyses trial run 4.

SPiCT trial run 5 (same as trial 4 but different uncertainties added to catch time-series)

See script and results in pdf file dab_trial_5.pdf:

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_5.pdf

Nearly the same results as previous trial. Slightly different Mohns Rho values. Results and diagnostics not shown here.

SPiCT trial run 6 (same as trial 5 but without early BTS index –> high uncertainties in index estimate)

See script and results in pdf file dab_trial_6.pdf

https://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/2014%20Meeting%20docs/08.%20Personal%20folders/dab.27.3a4/dab_trial_6.pdf

Uncertainties around estimates for absolute B and F increases drastically. Results with respect to relative B and F similar to previous runs but higher uncertainties around relative F, but still below the proxy reference. Retros for relative estimates better.

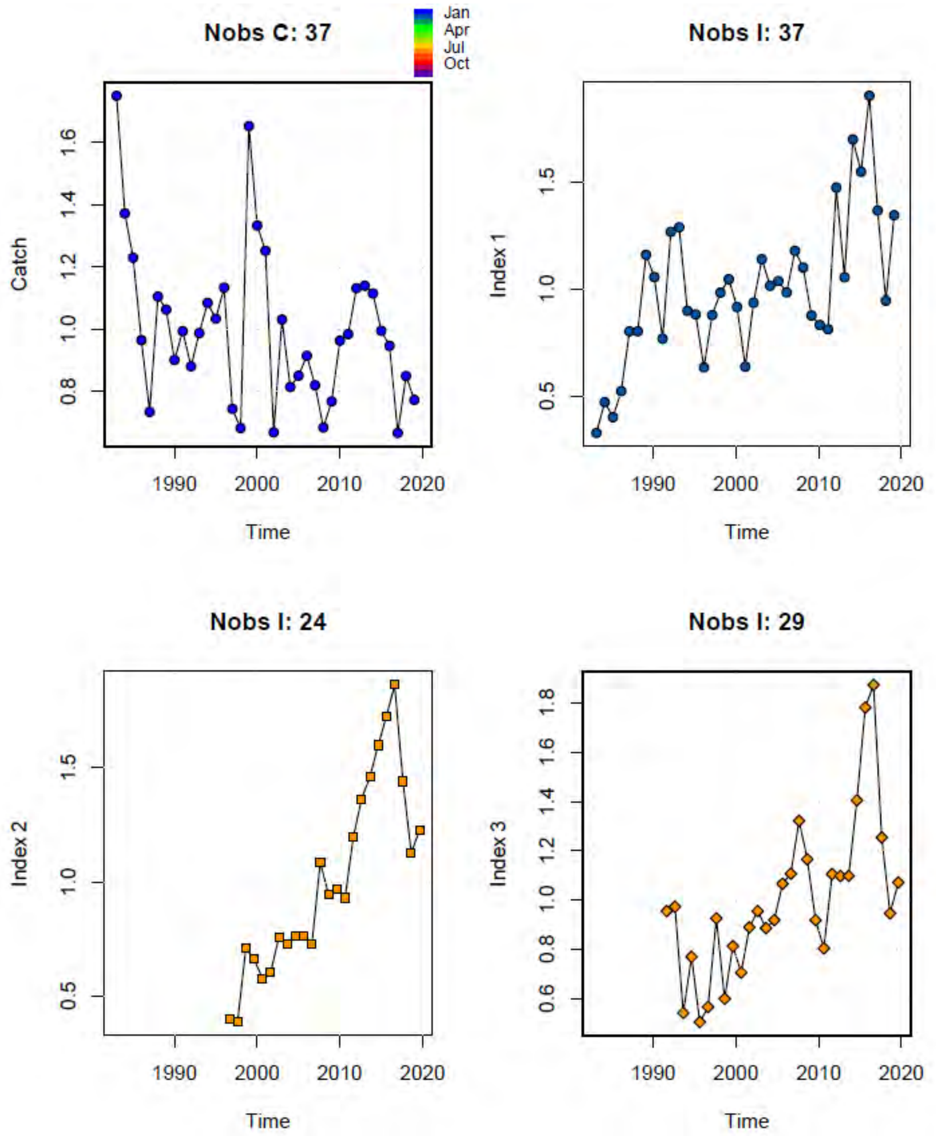

Figure 12.23. Dab (*Limanda limanda*). Input data trial run 6.

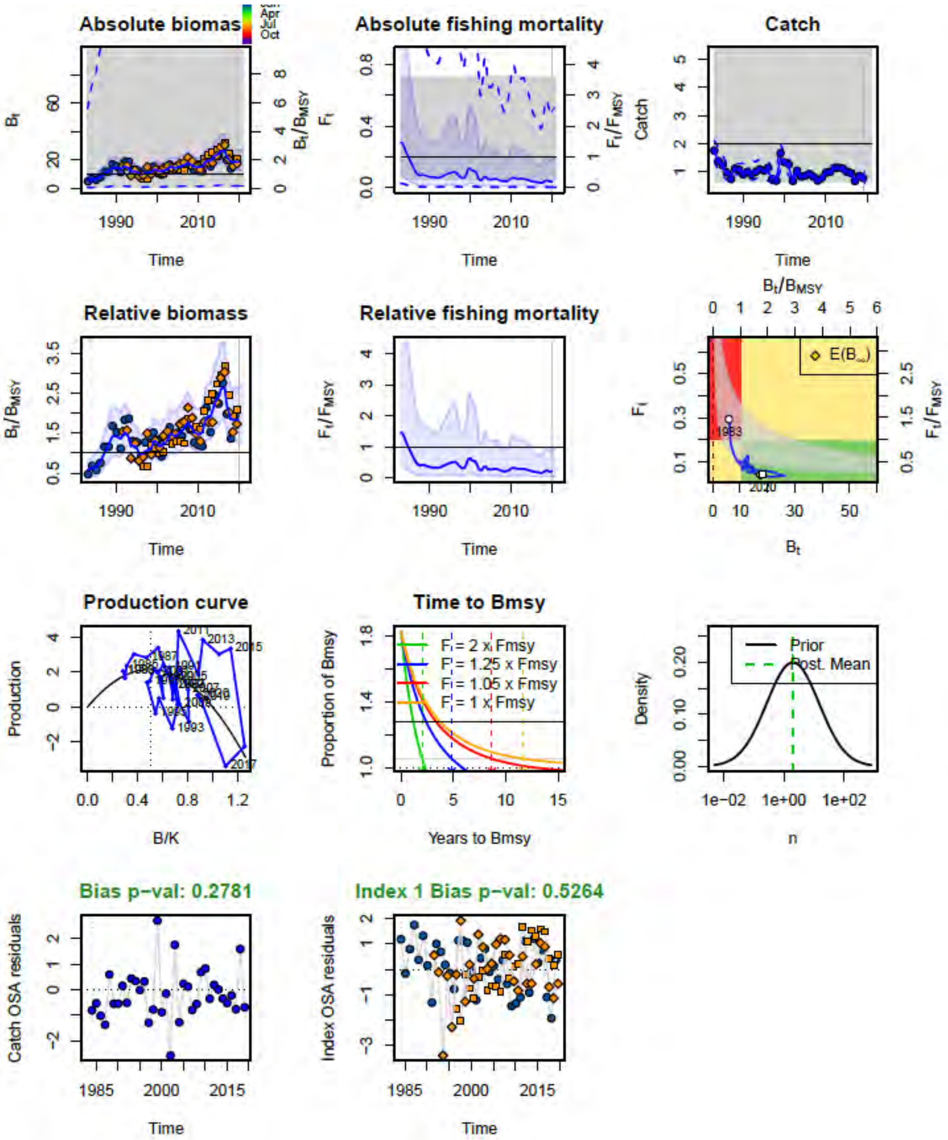

Figure 12.24. Dab (*Limanda limanda*). Results trial run 6.

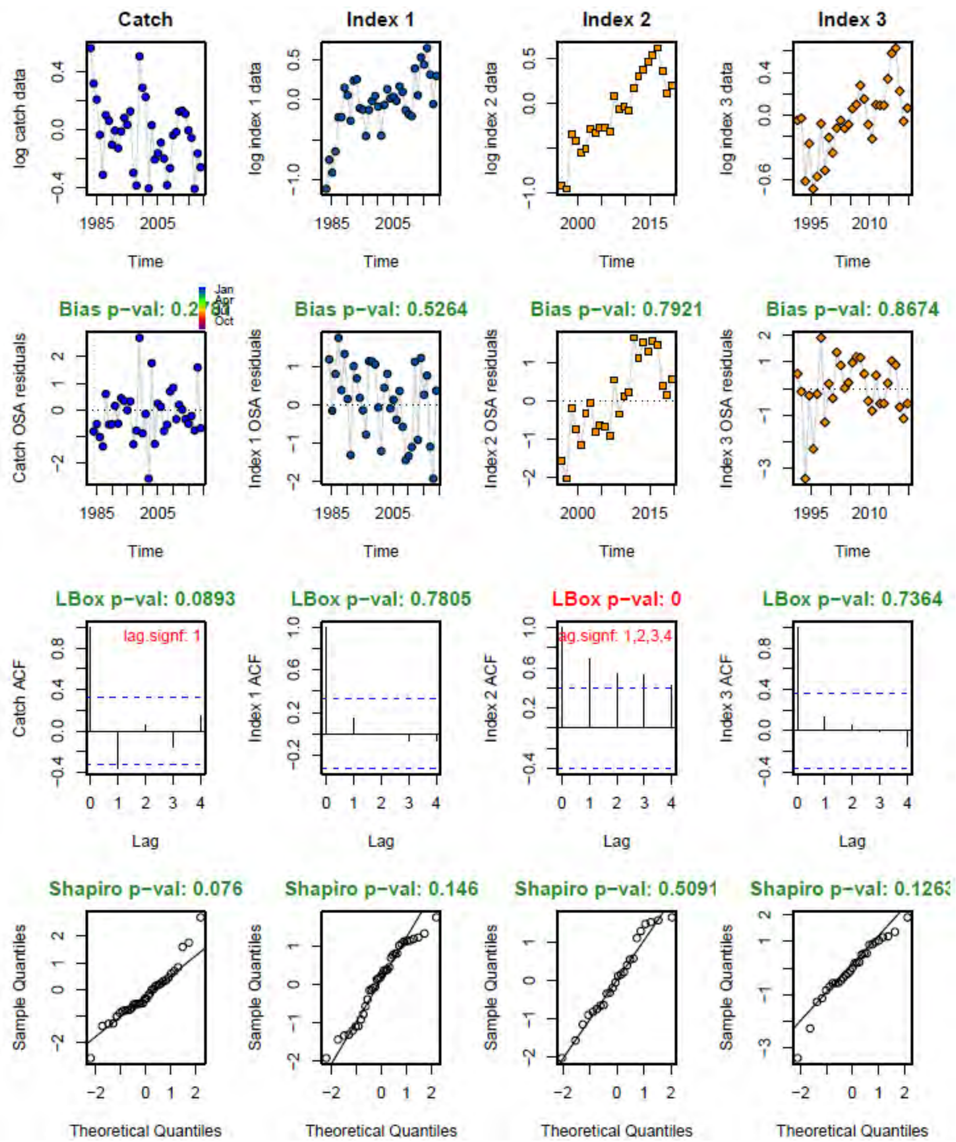

Figure 12.25. Dab (*Limanda limanda*). Diagnostics trial run 6.

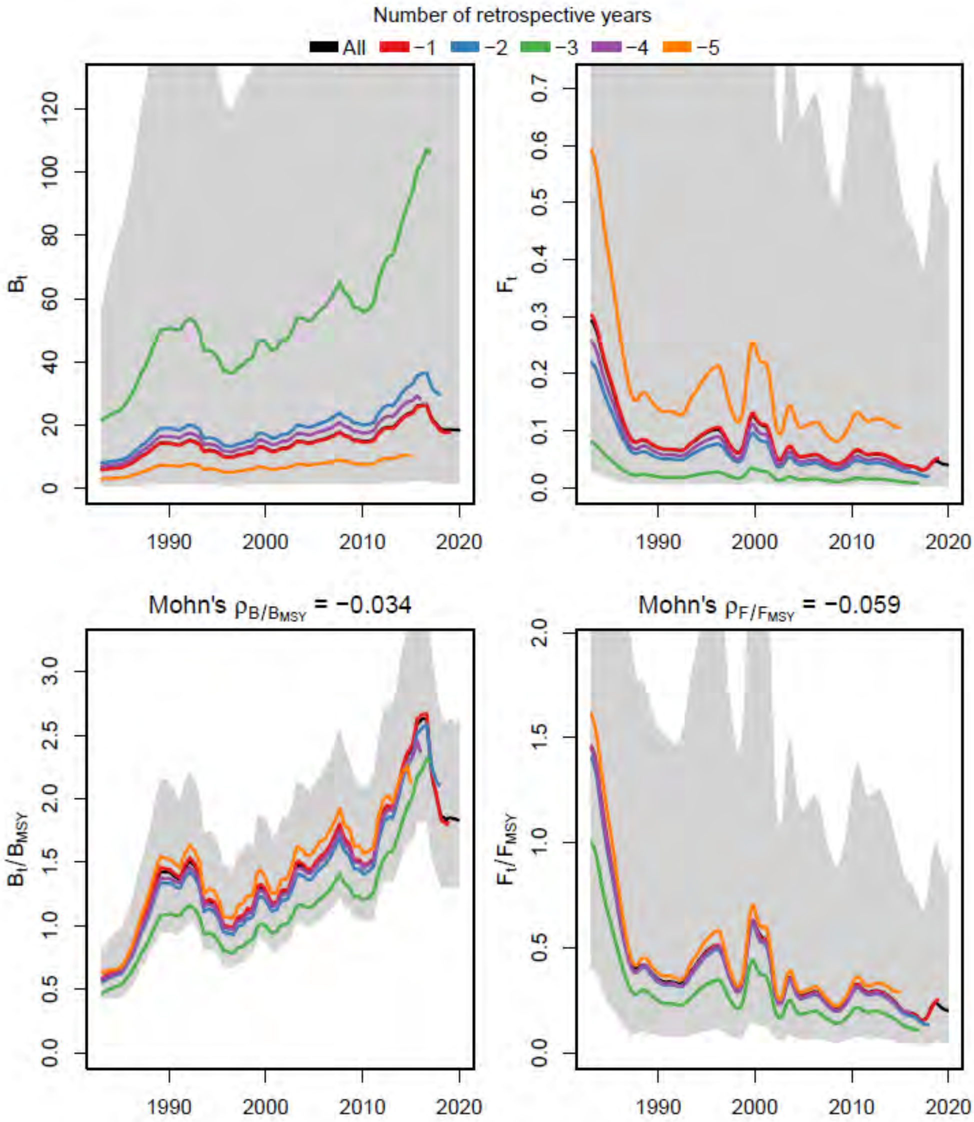

Figure 12.26. Dab (*Limanda limanda*). Retrospective analyses trial run 6.

12.4 Future considerations/recommendations

Further exploration of prior settings and sensitivity analyses are still to be done.

12.5 Reviewers report

Reviewers report is only provided for the stocks that were considered for the assessment benchmark meeting (15–19 February 2021).

12.6 References

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13 Cod (*Gadus morhua*) in Division 7.a (Irish Sea) (cod.27.7a)

13.1 Introduction

Cod in 7A has been last benchmarked at WKIrish in 2017 using age based (ASAP) model as a category 1 stock. Due to a very poor retrospective pattern the stock was in 2019 at the WGCSE downgraded to a category 3 stock using the 2 over 3 rule based in the quarter 1 survey biomass (Northern Ireland Groundfish survey).

The stock has been heavily fished since the mid-1960s leading to a strong decline in biomass and introduction of a cod recovery plan since 2000. Catches declined considerably in line with the cod recovery plan, however the stock failed to recover. The cod recovery plan triggered a range of measures, such as exclusion zones for cod as well as adaptation of *Nephrops* gear to avoid the bycatch of young and under MLS fish, while at the same time whitefish fleet targeting cod being considerably declined. Catches of mature cod reduced considerably. Both of those caused a change in selectivity and catchability of cod.

13.2 Input data for stock assessment (ToR 1 & 2)

Landings

Landings data have been supplied (annual quarterly landings) by the UK(N. Ireland), UK(E&W), UK(Scotland), Ireland, Belgium, and the IOM from databases maintained by national Government Departments and research agencies. The landings figures may be adjusted by national administrations or scientists to correct for known or estimated misreporting by area or species. To avoid double counting of landings data, each UK region supplies data for UK landings into its regional ports, and landings by its fleet into non-UK ports.

In addition, the stock coordinator compiles the international landings and catch-at-age data and maintains a time-series of such data with any amendments, since 2013 this has applied using 'InterCatch' protocols and compared with existing spreadsheet-based methods. These methods have been evaluated and provide similar results with negligible differences.

Historic adjustments to official landings data

The input data on fishery landings and age compositions are split into five periods:

1903–1967. Landings in this period are available, however the origin and quality are questionable.

1968–1990. Landings in this period, provided to ICES by stock coordinators from all countries, are assumed to be un-biased and are used directly as the input data to stock assessments.

1991–1999. TAC reductions in this period caused substantial misreporting of cod landings into several major ports in one country, mainly species misreporting. Landings into these ports were estimated based on observations of cod landings by different fleet sectors during regular port visits. For other national landings, the WG figures provided to ICES stock coordinators were used.

2000–2005. Cod recovery measures were considered to have caused significant problems with estimation of landings. The ICES WG landings data provided by stock coordinators for all countries are considered uncertain and estimated within an assessment model. Observations of misreported landings were available for 2000, 2001, 2002 and 2005. However, they have generally not been used to correct the reported landings but have been used to evaluate model estimates in those years.

2006–2019. The introduction of the UK buyers and sellers legislation is considered to have reduced the bias in the landings data but the level to which this has occurred is unknown. Consequently, comparisons were made between the fit of the model to recorded landings under an assumption of bias and unbiased information.

In addition to the above, Irish landings of cod reported from ICES rectangles immediately north of the Irish Sea/Celtic Sea boundary (ICES rectangles 33E2 and 33E3) have been reallocated into the Celtic Sea as they represent a combination of inaccurate area reporting and catches of cod considered by ICES to be part of the Celtic Sea stock.

A strong cohort was observed in 2013, resulting in an increased spawning biomass and the ASAP model, however, the fish did not spawn and disappeared at age 4 or 5. Those 2 factors were largely responsible for the failure of the ASAP model.

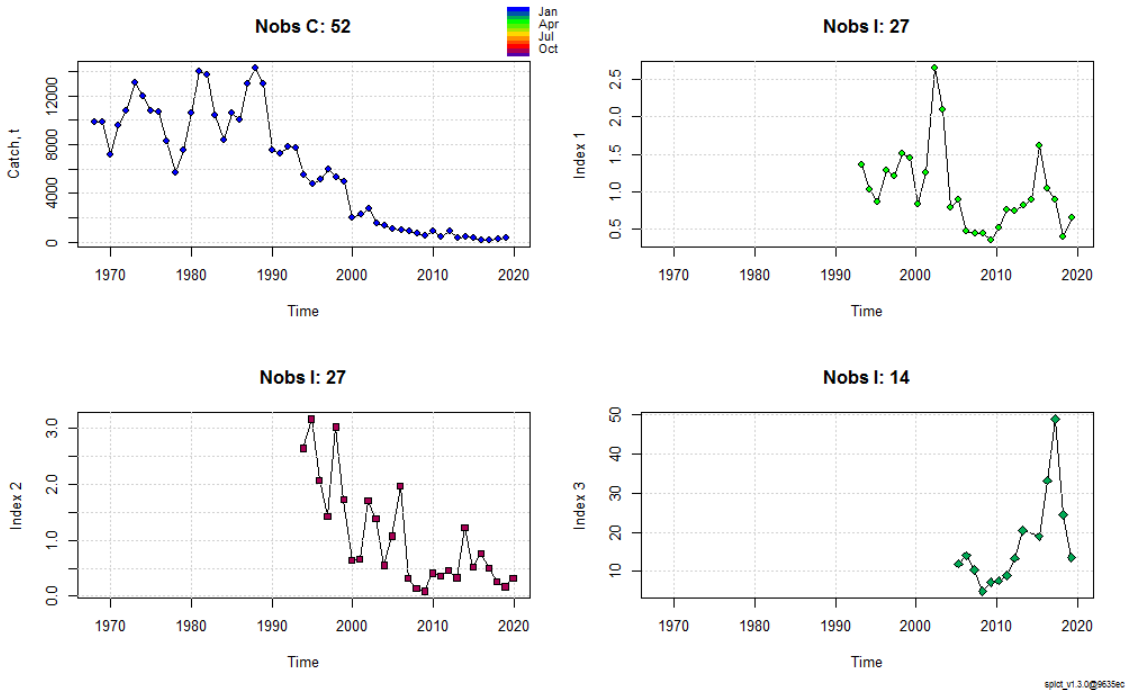
Discards

At WKROUND 2012 collation of recent discard information provided by Member States for the stock was carried out as a scoping exercise ready for future modelling and the provision of advice. Up to 2003, estimates of discards are available only from limited observer schemes and a self-sampling scheme. Observer data are collected using standard at-sea sampling schemes. Results have been reported to ICES. Discards data (numbers-at-age and/or length frequencies) have been supplied for 7.a cod by Ireland, UK (Northern Ireland) and UK(E&W) and Belgium. The data were supplied raised to the appropriate fleet/métier level by the Member States. These methods have been applied annual since WKROUND 2012, using InterCatch protocols with comparison to existing spreadsheet-based methods. The catch rates for the Northern Irish at-sea sampling scheme is shown in Figure 7.4.2, the plots show well resolved density plots of catch rates for the single rig (OTB), twin rig otter trawls (OTT) and midwater trawls (OTM) across the sampling period.

As an indication of confidence in the discard estimates derived from sampling schemes coefficients of variation were calculated. These have been provided the assessment working groups (WGCSE 2015) however; the series was extended to cover the entire time-series of catch sampling. Coefficients of variation were calculated for individual national schemes. The coefficients of variation for the Northern Irish at-sea sampling scheme were calculated to take into consideration the different of contribution of fleet segments to total fleet activity, weighted by quarterly contribution of gears to entire fleet activity (Cochran, 1977). Discard estimates were also calculated for cod from the fisher self-sampling scheme, used to provide samples for *Nephrops* discards (WKIrish 2). Comparison of these provides confidence in the ability of these schemes to provide robust estimates of discards. The CVs calculated for discard estimates of cod show a high level of interannual variation although no temporal trend or relationship with total discard volume is apparent. The sampling coverage of fleets was also assessed by comparing the observed and reported landings values. It is considered that there is consistent agreement in the estimate derived from at-sea sampling that that reported providing confidence in the design of the sampling scheme to provided estimates of catch for the sampled fleets.

Table 13.1. Available data.

Data	Timeframe	Ages	notes
Commercial fishery	1903–1967		landings only
Commercial fishery	1968–present	0–6+	Discards and landings, 2002–2005 unreliable due to political issues
Q1 Groundfish survey	1994–present	1–5	
FSP survey Q1	2005–present, excluding 2014	2–7	
Q4 Groundfish survey	1993–present	0–2	In recent years very sketchy



Further data description can be found in the WKIrish 2 report.

Table 13.2. Total Commercial catches and survey indices.

Year	Commercial	NIGSQ1	NIGSQ4	UKFSP
1968	9826	NA	NA	NA
1969	9889	NA	NA	NA
1970	7134	NA	NA	NA
1971	9609	NA	NA	NA
1972	10780	NA	NA	NA
1973	13041	NA	NA	NA
1974	12000	NA	NA	NA
1975	10720	NA	NA	NA
1976	10628	NA	NA	NA
1977	8255	NA	NA	NA
1978	5662	NA	NA	NA
1979	7548	NA	NA	NA
1980	10599	NA	NA	NA
1981	13958	NA	NA	NA
1982	13694	NA	NA	NA
1983	10387	NA	NA	NA
1984	8385	NA	NA	NA
1985	10544	NA	NA	NA
1986	10006	NA	NA	NA
1987	13022	NA	NA	NA
1988	14277	NA	NA	NA
1989	12953	NA	NA	NA
1990	7538	NA	NA	NA
1991	7258	NA	NA	NA
1992	7833	NA	NA	NA
1993	7710	1.355	2.6334	NA
1994	5544	1.023	3.1534	NA
1995	4753	0.865	2.0645	NA
1996	5104	1.285	1.4243	NA

Year	Commercial	NIGSQ1	NIGSQ4	UKFSP
1997	5979	1.212	3.0103	NA
1998	5347	1.504	1.7143	NA
1999	4943	1.447	0.6399	NA
2000	1973	0.837	0.665	NA
2001	2316	1.259	1.6993	NA
2002	2741	2.654	1.3744	NA
2003	1500	2.091	0.5529	NA
2004	1326	0.784	1.0722	NA
2005	1114	0.898	1.9613	11.9
2006	1025	0.469	0.3174	14
2007	847	0.445	0.1366	10.4
2008	723	0.435	0.0876	4.9
2009	554	0.347	0.4116	7.2
2010	850	0.514	0.3623	7.6
2011	413	0.748	0.4546	8.9
2012	876	0.739	0.3316	13.4
2013	358	0.815	1.2253	20.5
2014	397	0.889	0.5147	NA
2015	308	1.618	0.764	18.9
2016	142	1.039	0.4943	33.2
2017	143	0.891	0.2567	48.9
2018	257	0.399	0.1702	24.4
2019	302	0.656	0.3228	13.6

Catch data can be seen in the data folder.

13.3 Stock assessment (ToR 3)

A SPiCT model was discussed at the data evaluation meeting in November, and seen as not the most appropriate model, and that a stock synthesis or Jabba model (integrated model) might perform better for this particular stock. The SPiCT model seems not to be able to model shifts in productivity in the way that other models could.

Recommendations from the data evaluation benchmark consisted of:

- Running the SPiCT model with catches from 1903 (which were available from an old ICES report (?) but the quality of data is questionable;
- Set a prior for K;
- If running the SPiCT model from 1968 (as previously) the bfrac prior should be set to 0.5;
- Explore a stock synthesis model;
- Explore a Jabba model.

A SPiCT model was constructed using catches from 1903, total survey biomass of the Fisheries Science Partnership survey (FSP) and quarter 1 and quarter 4 Northern Ireland Groundfish Surveys (NIGFS).

Priors were set for the carrying capacity K.

Table 13.3. Default priors.

Prior	Default value and Stdev
k	80000, 0.2
n	2, 0.3
bfrac	1, 0.2
sdf	2, 0.1
sdc	0.1, 0.1
Dteuler	0.0125

The fishery underwent a change in fishing behaviour, which has been implemented in a five-ways and tested:

- No change;
- A stepwise change in 2000;
- A gradual change;
- A stepwise change using a Thorson prior;
- Gradual change with a Thorson prior.

In a next step a prior for the total biomass in 2010 was set to 6000, loosely based on stock assessments that have been conducted and can be assumed a good approximation for the year.

In a final iteration of the data, the time-series was shortened to 1968 and bfrac was set to 0.5, Biomass in 2010 was set to 6000 t.

The Table 13.4 shows the results (i.e. convergence, issues, retrospectives, sensitivity) to the various scenarios. SPiCT does not seem to perform well with the data, in particular if no biomass prior is set. While fits and convergence seem to be good in many of the scenarios, the actual results are unlikely, showing biomass and F levels that are either far too high or have very large confidence limits around them. Only scenarios 5 and 11 (full time-series with a stepwise change in fishing behaviour/MSY in 2000) and the restricted time-series with a gradual shift produced promising results. Long time-series of catches without indices seem to perform poorly, leading to very high confidence intervals around the Biomass and F.

From these analyses an assessment with SPiCT might not be the way forward for Irish Sea cod.

Table 13.4. Results of the scenarios run. Sensitivity and retrospective analysis were only performed for scenarios that looked promising.

Run number	dataset	priors	Sensitivity	convergence	retro	Other issues
1	1903	default		x		Good fit, however very unlikely results with high biomass values
2	1903	Default, gradual regime shift		x		Good diagnostic fit, unlikely output
3	1903	Default, stepwise regime shift 2000		x		Unlikely biomass results
4	1903	Default, Biomass (2010)-6000, 0.3		x		Better fit, poor shapiro value for catches, no correlations, however, large, increase rather than decrease in B over recent years.
5	1903	As run 4 Stepwise change in catchability in 2000	Out of 30, 7 did not converge, 1 trial fit failed, the remaining showed good sensitivity	x	FFmsy -0.17 BBmsy -0.04	Good fit, still poor shapiro value for catches, no correlations
6	1903	As Run 4, gradual regime shift		x		Poor fit for catch and quarter 4 survey, no production function, very large confidence interval around F and B
7	1903	As Run 4, Thorson prior stepwise in 1999		x		Reasonable fit, poor fit for catches
8	1903	As Run 4, Thorson prior gradual change		X Could not calculate stDev, result likely not true optimum		

Run number	dataset	priors	Sensitivity	convergence	retro	Other issues
9	1903	As Run 4, Gamma prior		No convergence		
10	1968	Default, Bfrac= 0.5, biomass(2010)=6,000		x		Good diagnostic fit however unlikely high biomass
11	1968	As Run 10, gradual shift	30 runs, no issues, good sensitivity to starting values	x	Some retros did not converge, FMSY -0.18, BMSY -0.03	Good diagnostic fit except catch OSA residuals, no correlations
12	1968	As run10 stepwise change in 2000		Optimization failed		
13	1968	As run 10, thorson prior stepwise change		x		Poor fit to catches
14	1968	As run 10, thorson gradual change		x	Ffmsy -0.24, Bmsy -0.02	Good diagnostic fit, no correlations, very wide confidence interval around F and Biomass
15	1968	As run 10, gamma prior		x		Good diagnostic fit, very wide confidence intervals around F and B prior to start of survey time-series.

Stock Synthesis

Further exploration was conducted into the application of stock synthesis, which is a more promising route to assess the Irish Sea cod stock. Stock synthesis has got considerably higher data demands, such as numbers-at-age or length for each of the surveys and catches, weight-at-age matrix, maturity-at-age, natural mortality.

Stock synthesis was explored with the following model options; however, it has not been peer reviewed as part of the working group.

The following parameters have been set:

Start year 1968 (catches from 1903 to 1968 are available but data source is unclear and by the data coordinator deemed not representative)

Ages 10 (including plus group)- as suggested by Henning

Fleets: Commercial, Q1 and Q4 IBTS Groundfish survey, Fisheries science partnership survey

M: estimated in breakpoints, initial values following Lorenzen distribution and fixed, ages > 3.5+ freely estimated with a prior set at 0.5

Growth model: von Bertalanffy

S–R function: Beverton–Holt, with recruitment deviation blocks starting in 1968

Selectivity: Selectivity pattern for commercial catches, Q1 survey and FSP survey were fixed for some ages and calculated empirical as random walk for the others. Q4 survey selectivity set to 1 for age 1, zero otherwise.

Evaluation of models was visually from diagnostics plots and from parameter estimation. Parameters close to limits were carefully tested and the suitability of the initial values and min-max examined.

Models that looked promising in:

- diagnostics
- results (i.e. no solution resulting in extreme M, SSB or biomass)
- fits

were further tested with a retrospective analysis.

A successful current result is displayed in the following, however, there are still values to be further tested. It seems preferable to use the dataset starting from 1968 than 1903 since previously no discards or biological data are available, and the origin of the data, while it is in ICES, is not well documented and values are highly uncertain.

13.4 Reviewers report

Reviewers report is only provided for the stocks that were considered for the assessment benchmark meeting (15–19 February 2021).

14 Sole (*Solea solea*) in Divisions 8c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (sol.27.8c9a)

14.1 Introduction

The common sole (*Solea solea*, Linnaeus, 1758) is a species of flatfish which is widely distributed in Northeast Atlantic shelf waters, from the northwest of Africa to southern Norway, including the North Sea, the western Baltic and the Mediterranean Sea. Inhabiting sandy and muddy bottoms (Quero *et al*., 1986), this species is generally targeted by multispecies fleets (gillnetters and trawlers) and has traditionally been considered of great relevance due to its high commercial value (Teixeira and Cabral, 2010).

The life cycle of common sole is complex and presents different ontogenetic migrations (Tanner *et al*., 2017). Common sole spawn in coastal waters at depths ranging from 30 to 100 m (van der Land, 1991). The spawning period is commonly between February and May, although it can occur in early winter in warmer areas. The development of the larvae is temperature-dependent and takes place in shallow waters (Tanner *et al*., 2017). It is during transport from spawning areas to coastal nurseries that the larvae metamorphose into benthic life (Marchand, 1993). Nursery areas are generally located within estuaries where juveniles of common sole spend up to two years in a residence phase before returning to the adult feeding and spawning areas on the continental shelf (e.g. Vasconcelos *et al*., 2010).

The unit management of the common sole stock in the Iberian Atlantic waters includes the ICES subdivisions 8.c and 9.a. where both the Portuguese and Spanish fleets operate. In this area common sole is target mainly by multispecies fleets using as main fishing gears trammel and gillnets.

The minimum landing size of sole is 24 cm. There are other regulations regarding the mesh size for trammel and trawl nets, fishing grounds and vessel's size. A precautionary Total Allowable Catch (TAC) is in place for all sole species (*Solea* spp.) in this area. Sole is under the Landing Obligation in divisions 8.abde (all bottom trawls, mesh sizes between 70 mm and 100 mm, all beam trawls, mesh sizes between 70 mm and 100 mm and all trammel and gillnets, mesh size larger or equal to 100 mm) and in Division 9.a (all trammelnets and gillnets, mesh size larger or equal to 100 mm). In Portugal, all catches of sole from all gears and mesh sizes are under the Landing Obligation (more restrictively than required by European regulations).

Although a combined TAC for all species of sole is advised, the assessment is only performed for the common sole. The last management advice for this stock was provided in 2019, and ICES advised that commercial landings should be no more than 502 tonnes in each of the years 2020 and 2021. The EU multiannual plan (MAP; EU, 2019) for stocks in the Western Waters and adjacent waters applies to this stock. The MAP stipulates that when the F_{MSY} ranges are not available, fishing opportunities should be based on the best available scientific advice.

At the moment, this stock is in category 5 and is going to be benchmarked in the WKWEST 2021 as well as the WKMSYSPiCT 2021. For the WKWEST 2021, an official data call was requested for this stock to get all the possible data, not only for the common sole (*S. Solea*) but also for the other sole species *Solea senegalensis, Pegusa lascaris* and Sole spp.

The first objective of this study is to compile and evaluate the available data of sol.27.8c9a in order to apply a stochastic production model in continuous time (SPiCT) (Pedersen and Berg, 2007). The second objective was to test different model configurations and values of priors to achieve a robust model for the stock.

14.2 Input data for stock assessment (ToR 1 & 2)

Commercial catches

From the recent data call, catches for *S. solea* are available in InterCatch from 2009 to 2019 (Figure 14.1). Information on discards indicates that discarding can be considered negligible (< 1%). For the years 2009–2010, only catches from Spain and France were available (Figure 14.2), while for the other years (2011–2019) catches are available for the three countries (i.e. Portugal, Spain and France). It worth to be mentioned that, during the WGBIE2020, Portuguese's colleagues highlight that catches from Portugal have a problem of misidentification in some ports with the three species (Dinis *et al.*, 2020). For this benchmark, using data from the Data Collection Framework (DCF) sampling, Portuguese catches were proportionally divided by sole species applying the species weight proportion to the total weight of Soleidae in each year, landing port, and semester and using a simple random sampling estimator, following Figueiredo *et al*. (2020) (see details in Annex 1 of the WD). At the moment catches are considered reliable.

From the "*Historical Nominal Catches from 2000–2010, Source: Eurostat/ICES database on catch statistics - ICES 2011, Copenhagen. Version 26-06-2019*" dataset, catches are available for S. sole for 2000–2010, but some years data were reported only by Portugal, others by Spain, and for this reason are considered possible underestimated (Figure 14.3). However, how this is the only information available, catches from 2000–2008 were used for the further analysis, taking into account this possible uncertainty.

When catches are analysed by division it is possible to see that the majority of them are in the Area 9a and that different métiers fish this stock. However, when the proportion of the catches by fleet on the total catches is computed (Table 14.1), it is possible to see that there are two main métiers that catch this stock, the "MIS_MIS_0_0_0" from Portugal and "GRT_DEF_60-79_0_0" from Spain.

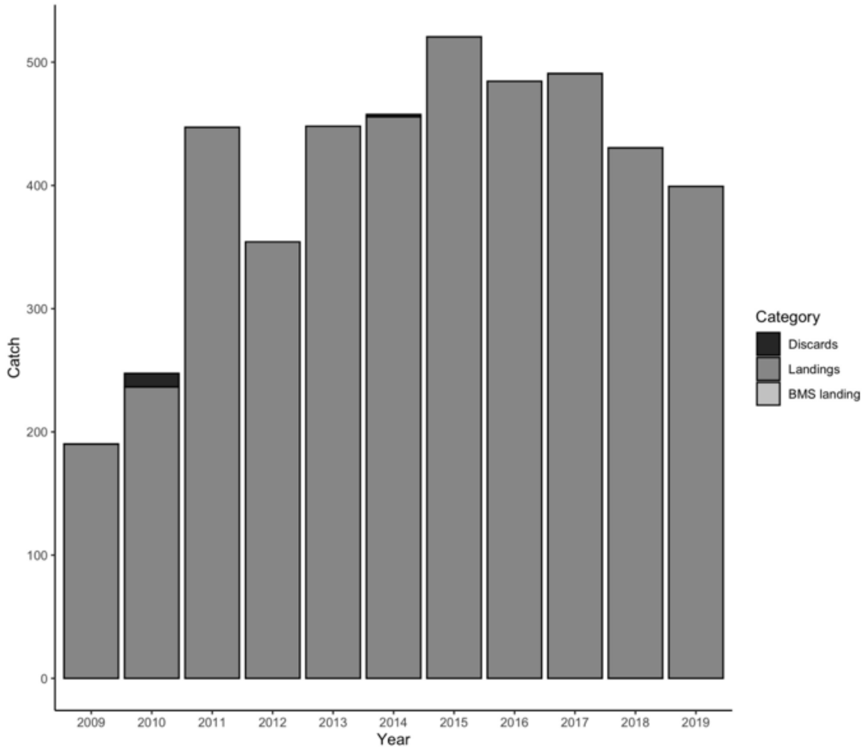


Figure 14.1. Catches for *Solea solea* by category in the ICES divisions 8c9a for Portugal, Spain and France from 2009 to 2019. Source data: InterCatch.

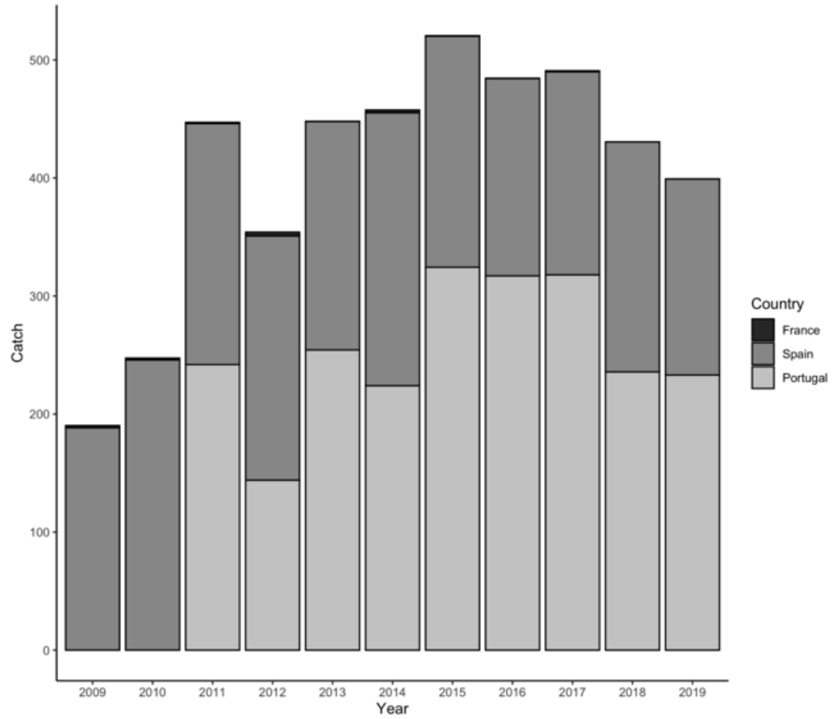


Figure 14.2. Catches for *Solea solea* by country in the ICES divisions 8c9a for Portugal, Spain and France from 2009 to 2019. Source data: InterCatch.

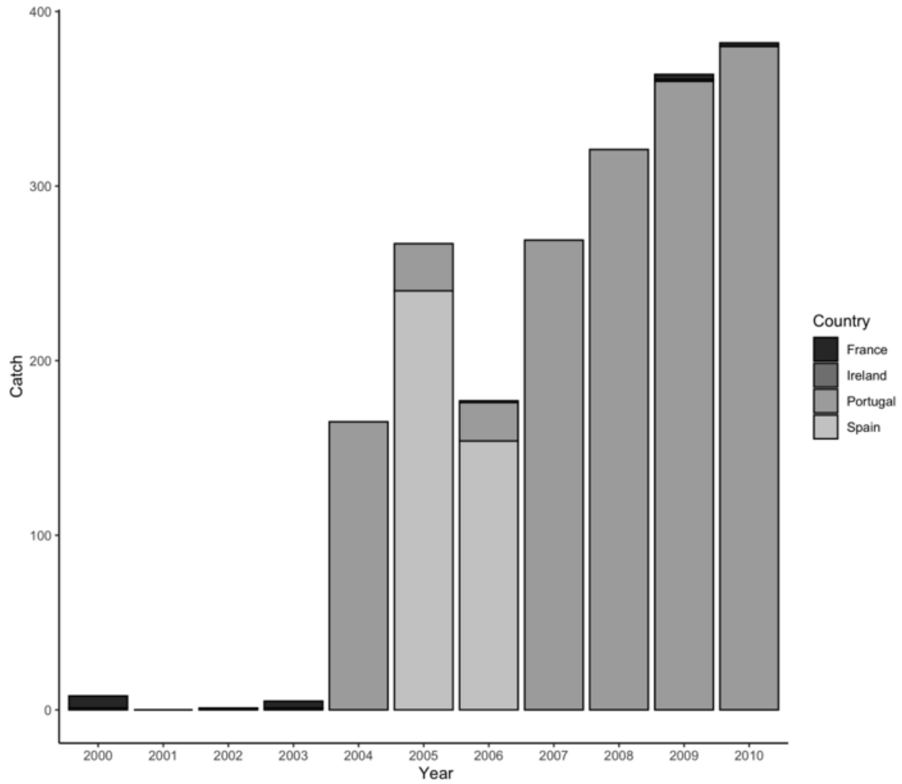


Figure 14.3. Catches for *Solea solea* by country in the ICES divisions 8c9a for Portugal, Spain, Ireland and France from 2000 to 2010. Source data: Eurostat/ICES database on catch statistics.

Table 14.1. Proportion of the catches by métier with respect the total catches by year.

Métier	2011	2012	2013	2014	2015	2016	2017	2018	2019
GNS_DEF100_119_0_0_all	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GNS_DEF_all_0_0_all	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GNS_DEF_60-79_0_0	0.05	0.17	0.04	0.03	0.02	0.03	0.04	0.07	0.25
GTR_DEF100-119_0_0_all	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GTR_DEF_60-79_0_0	0.24	0.14	0.18	0.21	0.19	0.18	0.19	0.21	0.10
GTR_DEF_40-59_0_0	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
GTR_CRU_0_0_0_all	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTB_CRU_>=70_0_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTB_DEF_>=55_0_0	0.08	0.13	0.08	0.10	0.06	0.03	0.06	0.09	0.02
OTB_DEF_>=70_0_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTB_MCD_>=55_0_0	0.01	0.07	0.05	0.07	0.03	0.03	0.02	0.04	0.02
OTB_MPD_>=55_0_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
OTB	0.05	0.05	0.03	0.05	0.03	0.04	0.04	0.07	0.04
OTT_DEF_>=70_0_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTT_CRU_>=70_0_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIS_MIS_0_0_0_HC	0.08	0.07	0.08	0.02	0.07	0.07	0.02	0.02	0.02
MIS_MIS_0_0_0	0.49	0.36	0.53	0.44	0.59	0.61	0.60	0.48	0.54

Length distribution of commercial catches

In InterCatch data of length distribution are available for the years 2011–2019 (Figure 14.5) from both Spain and Portugal. The majority of the data is of the polyvalent fleet (i.e. métier "MIS_MIS_0_0_0") from Portugal (Table 14.2), which is also the most important fleet for this stock.

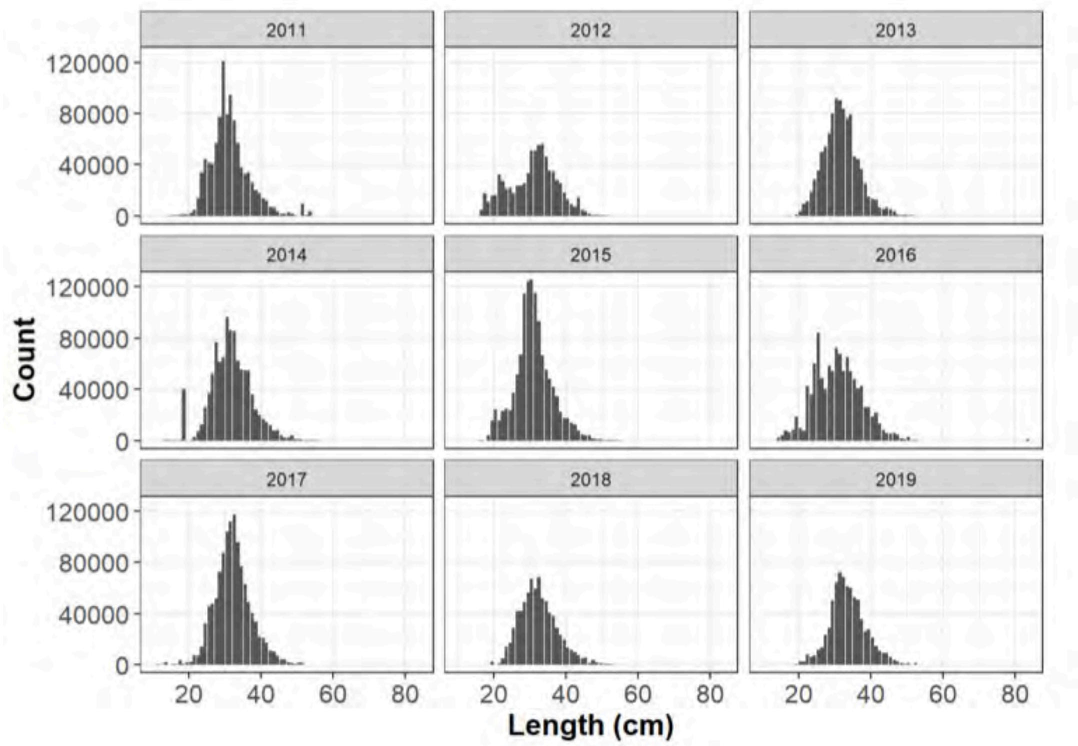


Figure 14.4. Length distribution of catches for *Solea solea* by year in the ICES divisions 8c9a for Portugal, Spain and France from 2011 to 2019. Source data: InterCatch.

Table 14.2. Proportion of catches of which length distribution data are available by fleets and year.

Year	OTB_MCD_>=55_0_0	GNS_DEF_60_79_0_0	OTB	OTB_DEF_>=55_0_0	GTR_DEF_60_79_0_0	MIS_MIS_0_0_0
2011	0.02	0.03	0.08	0.12		0.75
2012	0.11		0.08	0.22		0.59
2013	0.06		0.05	0.12		0.77
2014			0.07	0.13	0.20	0.60
2015	0.04		0.04	0.08		0.84
2016	0.03		0.06	0.05		0.86
2017	0.01	0.02	0.05	0.08	0.10	0.74
2018			0.11	0.14		0.75
2019		0.13	0.05	0.03	0.07	0.72

Spanish abundance index from scientific survey

Common sole data were collected during the scientific survey series SP-NSGFS Q4 performed by the Instituto Español de Oceanografía (IEO) in autumn (September and October) between 2000 and 2019. Surveys were conducted on the northern continental shelf of the Iberian Peninsula (ICES Division 8c and the northern part of 9a) which has a total surface area of almost 18 000 km^2 (Figure 14.5). The sea bottom composition of this area is mainly rock or sand sediments until 100 m of depth. Below 100 m depth, muddy bottoms characterize the Galician waters (ICES Division 9a) whereas rocky ground and deep canyons are typical in the Cantabrian Sea (ICES Division 8c) (Abad *et al.*, 2020). Surveys were performed using a stratified sampling design based on depth with three bathymetric strata: 70–120 m, 121–200 m and 201–500 m. Sampling stations consisted of 30 minute trawling hauls located randomly within each stratum at the beginning of the design. The gear used is the baka 44/60 and the survey follow the protocol of the International Bottom Trawl Survey Working Group (IBTSWG) of ICES (ICES, 2017).

Figure 14.5. Map of the study area. Black dots represent annual sampling locations.

The common sole (*Solea solea*) is a species with a biological bathymetric range between 0 and 200 meters in the Iberian Atlantic waters. The SP-NSGFS Q4 only covers partially the common sole bathymetric range and the resultant abundance index is probably underestimated. For this reason, and with the aim to correct this sampling bias, we applied to this dataset a hurdle Bayesian spatio-temporal. Two variables were analysed in order to characterize the spatio-temporal behaviour of common sole individuals. Firstly, a presence/absence variable was considered to measure the occurrence probability of the species. Secondly, the weight by haul (kg) was used as an indicator of the conditional-to-presence abundance of the species. In addition, a bathymetric shared effect was included in the model as described in Paradinas *et al*. (2017, 2020) in order to integrate information on both the occurrence and the conditional-to-presence abundance to better fit informed environmental effects and avoid the violation of the aforementioned independence assumption. Bathymetry values were retrieved from the European Marine Observation and Data Network (EMODnet, http://www.emodnet.eu/) with a spatial resolution of 0.02 x 0.02 decimal degrees (20 m).

Models were fitted using the integrated nested Laplace approximation approach INLA (Rue *et al*., 2009) in the R software (R Core Team, 2020). The spatial component was modelled using the spatial partial differential equations (SPDE) module (Lindgren *et al*., 2011) of INLA and implementing a multivariate Gaussian distribution with zero mean and a Matérn covariance matrix. This matrix depends on the distance between locations and two hyperparameters, r_w and σ_w representing the range and the variance of the spatial effect respectively (Muñoz *et al*., 2013). As spatio-temporal structure we used the progressive one (Paradinas *et al*., 2017, 2020), which contains an autoregressive ϱ parameter that controls the degree of autocorrelation between consecutive years. In addition, an extra temporal effect g(t) was added using a second order random walk (RW2) prior to allow non-linear effects. In the presence of bathymetric and spatial autocorrelation terms, g(t) can be regarded as a spatially standardized stock size temporal trend.

The Bayesian approach requires prior distributions for all the parameters of the model and vague prior distributions for the dispersion and precision of the conditional-to-presence-abundance and median size models respectively. Following this approach, the fixed effects and the scaling parameter of the shared effects were assigned. Penalised complexity priors (i.e. PC priors, weak informative priors; Simpson *et al*., 2017) were assigned so that the probability of the spatial effect range being smaller than 0.5 degrees was 0.05, and the probability of the spatial effect variance being larger than 0.5 was 0.5. PC priors were also used for the variance of the bathymetric and the temporal trend RW2 effects. Specifically, the size of these effects was constrained by setting a 0.05 probability that sigma was greater than 0.5 and 1 respectively. Sensitivity analysis for the selection of priors was performed by testing different priors and verifying that the posterior distributions were consistent and concentrated comfortably within the support of the priors.

From this analysis, the most important results that we obtained are the predicted distribution of the species (Figure 14.6) and a new spatio-temporal abundance index (Figure 14.7).

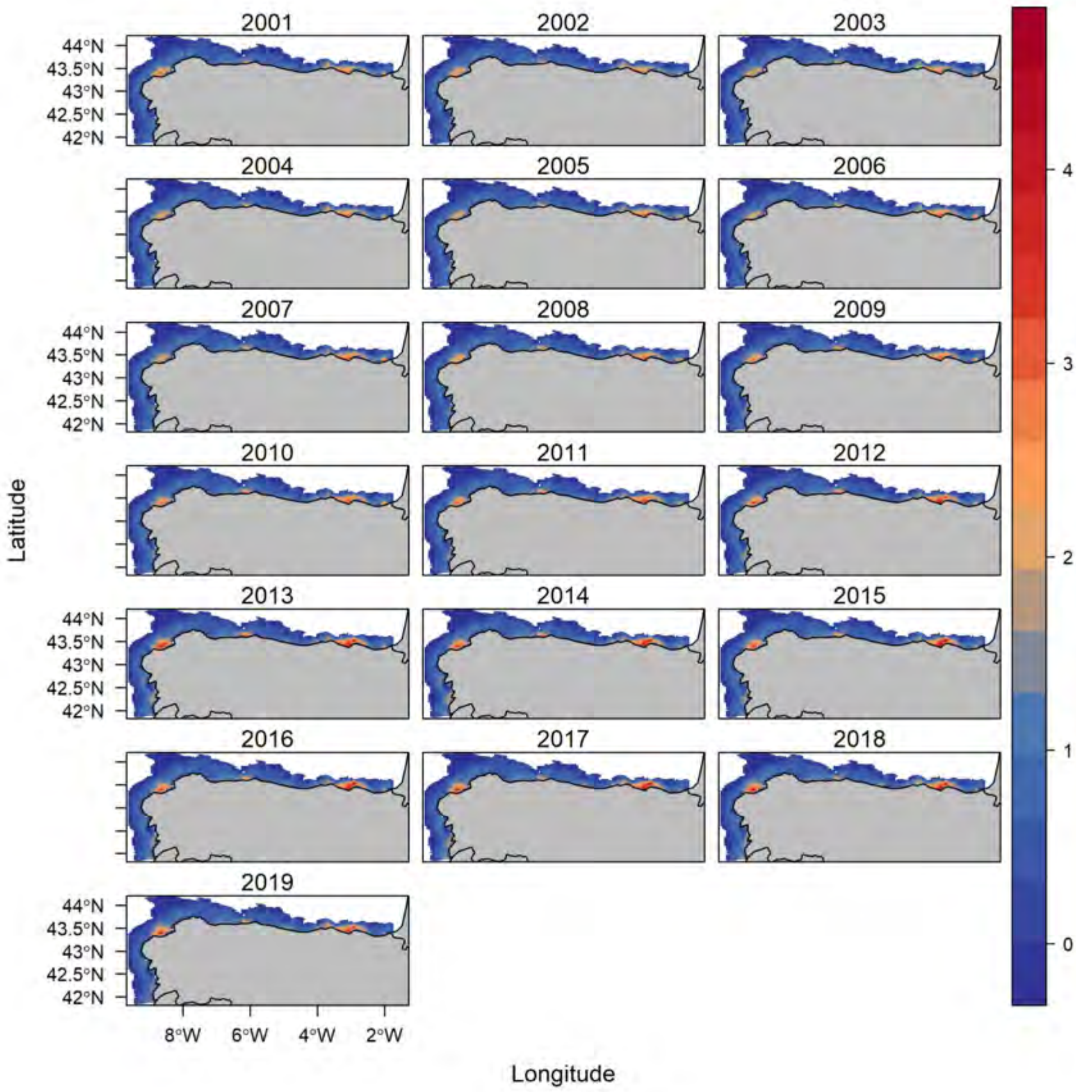


Figure 14.6. Prediction maps (2001–2019) of the common sole conditional-to presence median abundance estimated by the hurdle Bayesian spatio-temporal model.

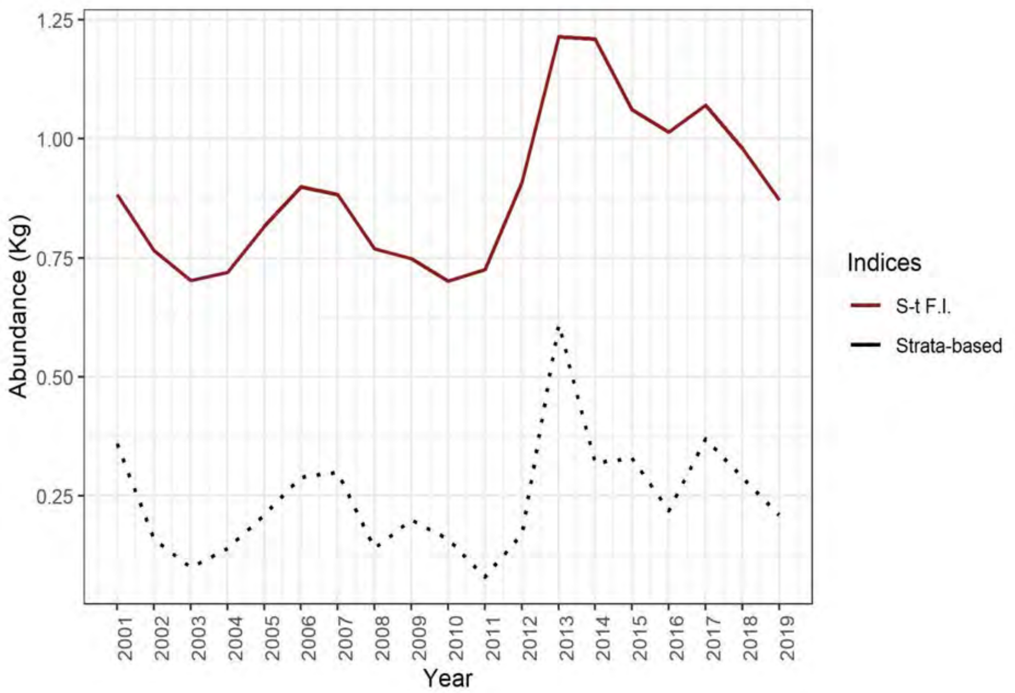


Figure 14.7. Temporal trend of the spatio-temporal abundance index (red) and the designed-based index for the SP-NSGFS Q4.

Catch Per Unit of Effort (CPUE) from Spain

Fishery-dependent data were collected by the Galician government Technical Unit of Artisanal Fisheries (Unidade Técnica de Pesca de Baixura, UTPB, in Galician). Usually, an on-board observer is assigned to fishing vessels randomly selected from this sector and covers the full set of multiple gears used in Galician waters and all along the geographical range (Figure 14.8) In a single trip each vessel usually performs several hauls. At each haul, observers record all basic operational data (i.e. date, geographical position, gear, etc.) and the number and weight of all retained and discarded taxa. The analysed database in this study counts 4350 hauls for which common sole was caught from January 2000 until December 2018.

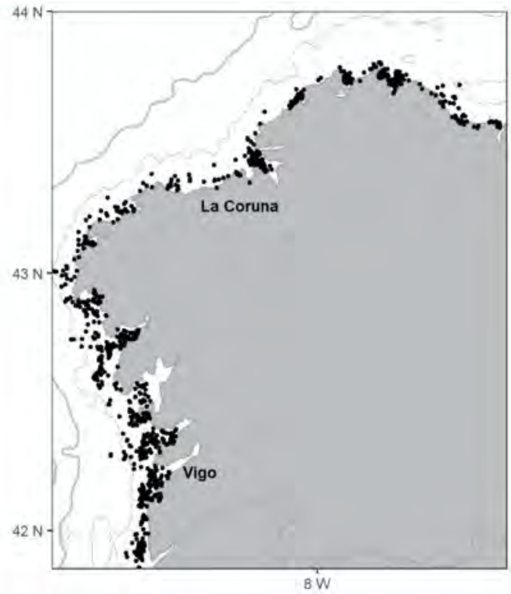


Figure 14.8. Data collected by observer on board on trammelnet fleet in Galicia (Spain) from 2000–2018 for common sole (*S. Solea*).

Before fitting any model, we selected the data for the trammelnet, which is the most representative gear for the common sole in order to reduce sources of variation. This selection was based on three criteria: i) proportion of hauls with zero catch, ii) total number of individuals sampled and iii) the spatio-temporal coverage. The first and second criterion was used as proxies of gear catchability and thus constant catchability was assumed along the time-series.

An exploratory analysis highlighted that common sole data have two main features, namely strong spatial and temporal dependence and a large proportion of observed zeros (i.e. zero inflated data). For this reason, we applied the same hurdle Bayesian spatio-temporal models that we performed for the SP-NSGFS Q4 data. As environmental variables we included bathymetry and type of substratum, both present in the dataset. Bathymetry was fitted using a non-linear RW2 effect. Gear saturation can exert a significant nonlinear effect on catchability, thus preliminary models included it, but was left out of the final model due to its negligible contribution to the model. In addition to the spatio-temporal correlation structure (i.e. same of model above) we fitted a cyclic non-linear month effect to capture the intra-annual variability of the abundance. The remaining potential source of abundance variability could be driven by the differences between vessels, caused by a skipper effect or unobserved gear characteristics. To remove bias caused by vessel-specific differences in fishing operation, we included a vessel random effect. The final CPUE index is showed in Figure 14.9.

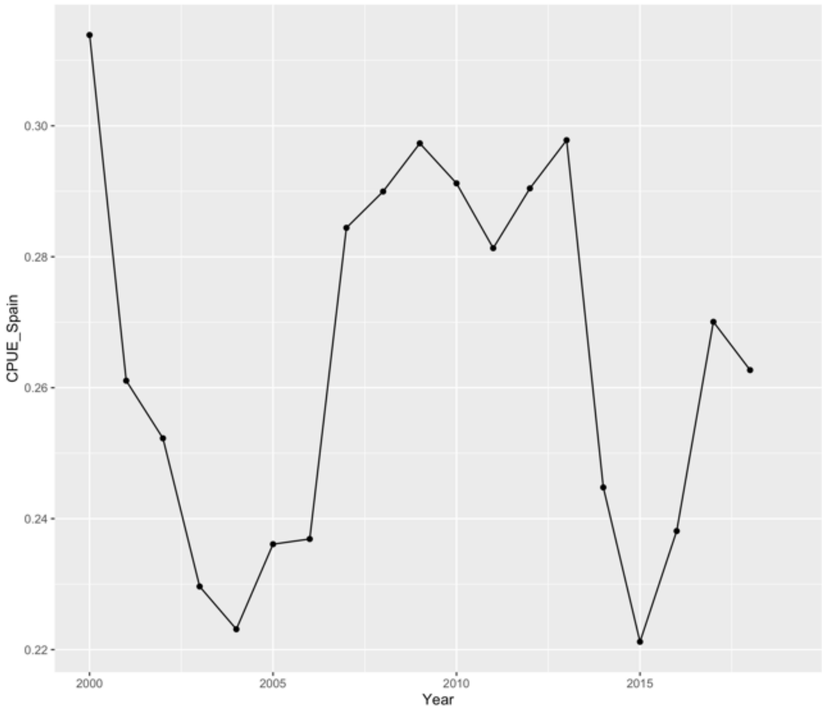


Figure 14.9. CPUE index derived from the hurdle Bayesian spatio-temporal model for 2000-2018 for common sole (*S. Solea*).

Portuguese survey data

The Portuguese Groundfish Survey (PtGFS-WIBTS-Q4) has been conducted by the Portuguese Institute for the Sea and Atmosphere (IPMA) and covers Division 9a in Portuguese continental waters (from latitude 41°20’N to 36°30’N). The survey is mainly conducted at the beginning of the 4th quarter, in October, and aims to monitor the abundance and distribution of *Merluccius merluccius* (hake) and *Trachurus trachurus* (horse mackerel) recruitment. Data on all Soleidae species caught is collected in this survey, including species identification, number of specimens caught and weight. The surveys have been carried with the Portuguese RV “Noruega”, which is a stern trawler of 47.5 m LOA, 1500 HP and 495 GRT and using a Norwegian Campelen Trawl (1800/96 NCT) gear with a 20 mm codend mesh size and ground rope with bobbins. PT-GFS fishing operations are performed during daylight and the duration of each tow changed in 2002, from 60 to 30 minutes. The sampling scheme is based on a systematic and stratified random sampling covering depths from 20 to 500 m, following the standard IBTS methodology for the western and southern areas (ICES, 2017). The mixed systematic and stratified sampling scheme comprises 66 fixed and 30 random trawl positions. In 2018, due to technical problems in the RV “Noruega” part of the survey was conducted on the commercial trawler “Calypso” (24.8 m LOA, 7215 GRT), using a CAR bottom trawl net type FGAV019, without rollers in the ground rope, and covering the centre and southwest coasts (sectors: LIS, SIN, MIL and ARR). In 2012 and 2019 no survey was conducted. In December 2020, the survey is planned to be conducted in a new vessel, RV “Mário Ruivo” (72.6 m LOA, and 2290 GRT) using a similar NCT net but with differences in the ground rope and bobbins.

Data from the annual Portuguese Groundfish Survey were provided by the Instituto Português do Mar e da Atmosfera (IPMA) from 2000 to 2018. Despite of the partially overlay between the survey and *Solea solea* distribution in Portuguese waters (Cabral *et al.*, 2012) references preferential empirical bathymetrical range, as assumed by fishermen, to be between 50 and 150 m), the species is rarely caught and numbers per hour are very low (Figure 14.10). Both the number of hauls and the proportion of hauls with catches of the species are very low (Figure 14.11). The fishing gear used in this survey has low catchability for the species and it is considered inadequate for monitoring its populations.

The catchability of this survey for the common sole species is worst with respect the Spanish in both spatial and temporal coverage and for this reason was dismissed as a biomass index for further analysis.

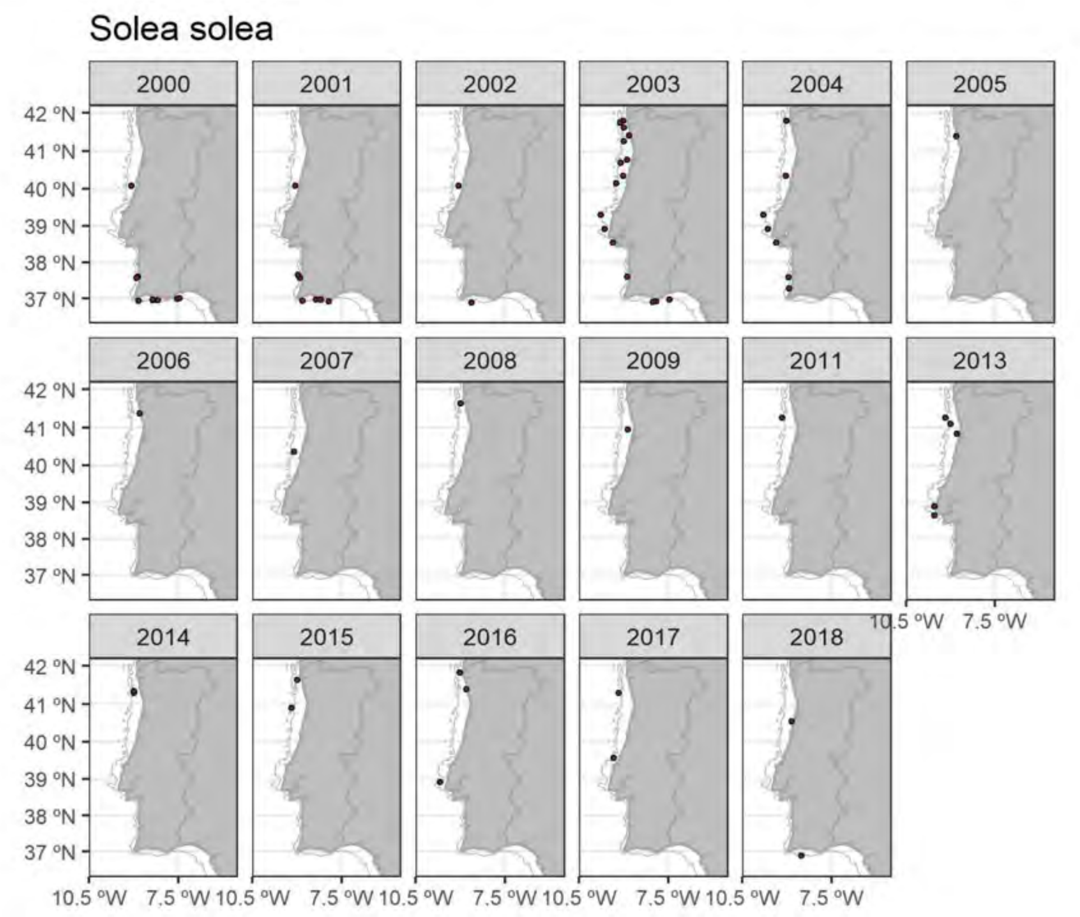


Figure 14.10. Dots indicates hauls where the species *S. Solea* was present by year.

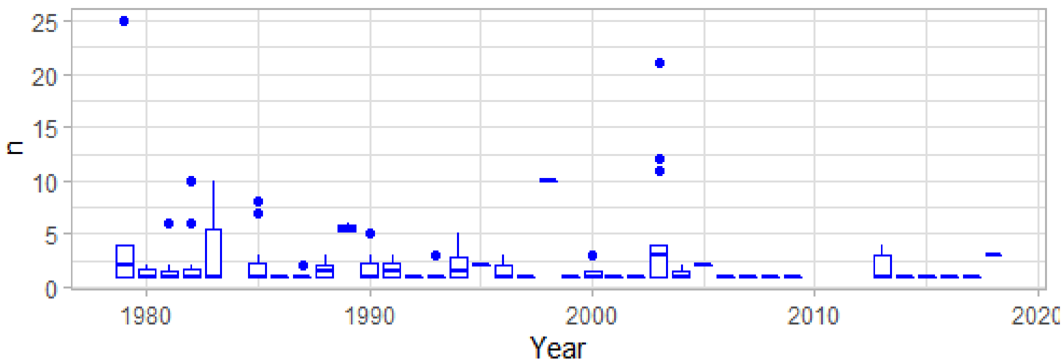


Figure 14.11. Boxplots of the number of *Solea solea* individuals caught per hour in the Portuguese Groundfish Survey.

Landing for unit effort of the polyvalent fleet in Portuguese waters (Division 9a)

The LPUE estimates relied on fishery-dependent data derived from the Portuguese polyvalent fleet and are based on the estimated *S. solea* landed weight by fishing trip (see Annex 1 of the WD to more information on data). The analysis was restricted to the most important landing ports in term of *S. solea* landed weight: Viana do Castelo, Matosinhos, Aveiro, Peniche and Setúbal.

The Portuguese polyvalent fleet segment comprises multi-gear/multispecies fisheries, usually licensed to operate with more than one fishing gear (most commonly gill and trammelnets, longlines and traps), that can be deployed in the same trip, targeting different species. The time period considered in the present study extends from 2011 to 2019.

The dataset was subset to trips with positive landings of the species. The LPUE standardization procedure was done via the adjustment of a GLM model to the matrix data, where the response variable was the *S. solea* landed weight by trip (unit effort). Several variables were evaluated as candidate to be included in the model: region, port, year, semester, quarter, month and vessel size group (<9 m and >9 m).

All the explanatory variables were considered as categorical variables. The function "bestglm" implemented in R software was used to select the best subset of explanatory variables (McLeod and Xu, 2010). The selection of the set explanatory variables to enter into the model is done following McLeod and Xu (2010) procedure, which is based on a variety of information criteria and their comparison following a simple exhaustive search algorithm (Morgan and Tatar, 1972).

The diagnostic plots, distribution of residuals and the quantile-quantile (Q-Q) plots, were used to assess model fitting. Changes in deviance explained by the selected model and the proportions of deviance explained to the total explained deviance was determined and used as indicative of R2. Annual estimates of LPUE and the corresponding standard error were determined for a reference condition where one level of each explanatory variable other the Year is fixed. All the statistical analysis was performed using R programming language, version 3.6.2 (R Development Core Team, 2020).

Data overview

Most *S. solea* landings were derived from the polyvalent fleet (between 87 and 95% for the period 2011–2019, Table 14.3). The dataset used to estimate LPUE was constrained to landing ports of Viana do Castelo, Matosinhos, Aveiro, Peniche and Setúbal. For the period 2011–2019, these five landings ports were the ones more frequently included in the top five ports with the highest *S. solea* annual total landed weight.

Table 14.3. *Solea solea* in Portuguese waters (Division 9a). *Solea solea* estimated landed weight per fleet, polyvalent and trawl, for the period 2011–2019. Percentages of the total national landed weight are present in brackets.

Year	Polyvalent (in Ton)	Trawl (in Ton)
2011	219.2 (90.6%)	22.7 (9.4%)
2012	126.5 (87.8%)	17.5 (12.2%)
2013	239.6 (94.2%)	14.7 (5.8%)
2014	201.8 (90.1%)	22.1 (9.9%)
2015	308.9 (95.2%)	15.5 (4.8%)
2016	296 (93.4%)	21 (6.6%)
2017	296.9 (93.4%)	21 (6.6%)
2018	205.6 (87.3%)	30 (12.7%)
2019	217.2 (93.3%)	15.7 (6.7%)

For each year, landing port and vessel size (<9 m or >9 m), the 1st, 2nd, 3rd and 4th quantiles of the number of trips, of the annual landed weight and of the average landed weight per trip were estimated. For each landing port, year and vessel size group, the vessels with occasional landings and reduced activity on the species capture were excluded if the annual number of trips, total annual landed weight and average landed weight per fishing trip were smaller than the correspondent 1st quantile. For the selected landing port, the total landed weigh of the excluded vessels represented between 3–7% of the total.

There was a high density of fishing trips with landed weight close to zero, as well as, the presence of some fishing trips with very high values. The LPUE analysis proceeded with the exclusion of very high values of landed weight per fishing trip, i.e. fishing trips with landed weight above 95% quantile corresponding to 35 kg.trip$_{-1}$).

The GLM model with the best adjustment included the explanatory variables year, month, landing port and vessel size and can be expressed as:

glm(LPUE ~ Year + Month + Port+ Vessel size, family=Gamma)

The value of R^2 was about 87% and the annual standardized mean LPUE is presented in Figure 14.12. This standardized LPUE was fitted using estimated marginal means (R package: emmeans).

Finally, to test the model sensitivity different runs of the GLM were performed reducing and increasing each time the weight per trip. All the runs were consistent and this index was considered reliable.

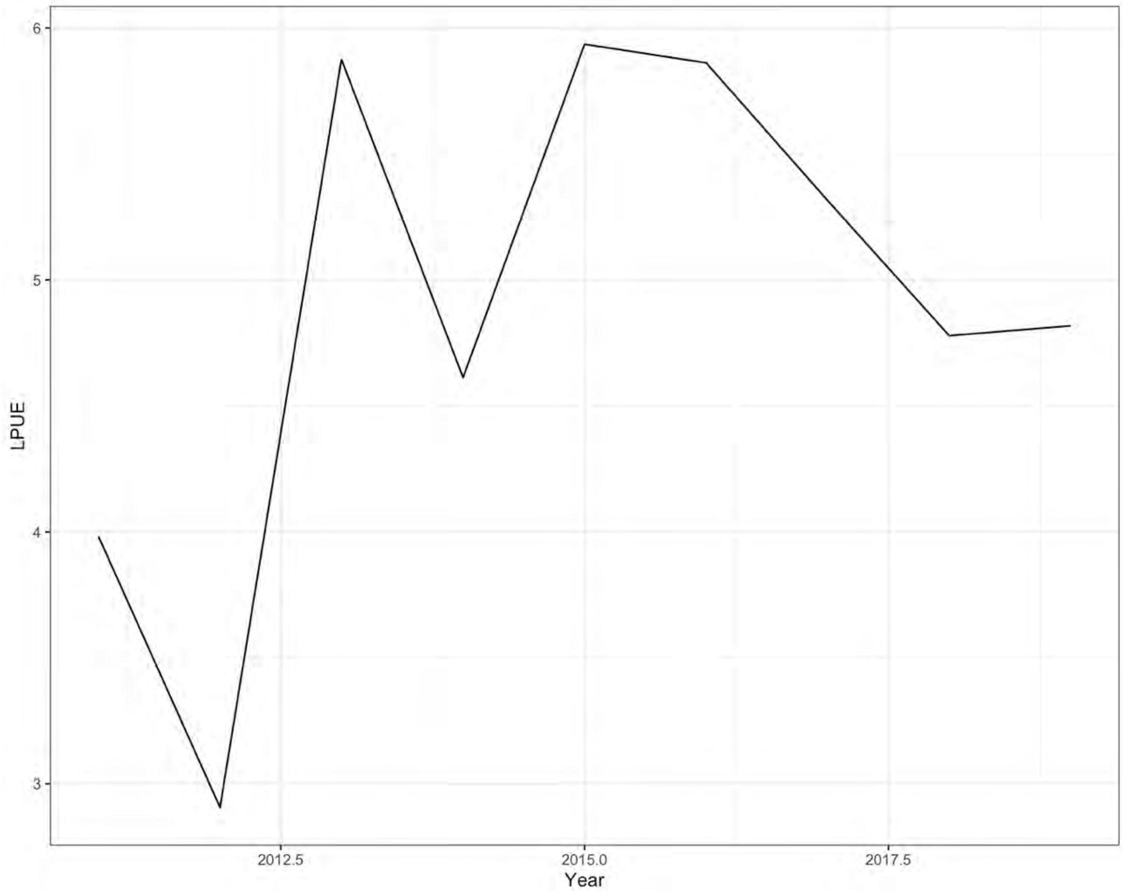


Figure 14.2. Standardized LPUE index (kg.trip-1) for the Portuguese polyvalent fishery with LOA >9m from 2011 to 2019.

14.3 Stock assessment (ToR 3)

The stock assessment was performed using the software SPiCT v1.3.3 (Pedersen and Berg, 2017) available at https://github.com/DTUAqua/spict.

As input data we used: 1) the catch data officially reported to ICES by Spain Portugal and France in divisions 8.c and 9.a from 2009–2019 and 2000–2008, catches were extracted from the historical ICES database. As mentioned in the precedent sections, for this time-series the observation noise was not constant in time. Indeed, there is some evidence that the common sole catch could be misclassified in the past, which means that common sole official landings might not then have corresponded only to this species but a mix of sole species. As in the SPiCT, it is possible to add knowledge that certain datapoints are more uncertain than others, the first eight years of the catch were considered uncertain relative to the remaining time-series and therefore are scaled by a factor 5. In particular using the stdevfacC vector that contains the factor that is multiplied onto the standard deviation of the datapoints of the corresponding observation vector.

Catch data must be supplemented in the SPiCT model by at least one independent abundance index. An important advantage of SPiCT over other surplus production models is that it allows the use of multiple abundance indices with different time-series in addition to the catch time-series. Here we performed different runs using: 1) the Spanish survey abundance index; 2) the spatio-temporal abundance index produced with the hurdle Bayesian spatial-temporal model; 3) the Spanish CPUE; and 4) the Portuguese LPUE. In all the runs these indexes were used in combination or alone to test the model sensitivity to them.

The continuous-time SPiCT formulation, time-stepping is achieved through a Euler scheme with a default time increment equal to 1/16 (where time is measured in years).

As common sole catch data were collected annually, the discrete-time realisation of SPiCT, obtained by setting the time-step dtEuler equal to one, was considered sufficient.

Twelve different runs were tested for this stock using:

- default priors,
- fixing n to resemble the Schaefer production model,
- setting the priors for the ratio between biomass in the initial year relative to K, mean of log(0.5) and sd of 0.2,
- setting priors for the ratio between biomass in the initial year relative to K, mean of log(0.3) and sd of 1.

For each run the checklist for the acceptance of the SPiCT was performed. This procedure consisted in verify:

- Model convergence. All the scenarios fitted converged.
- No violation of model assumptions based on one-step-ahead residuals (bias, autocorrelation, normality). In many cases these assumptions were violated.
- All variance parameters of the model parameters are finite should be TRUE. In all cases the variance equal to true was achieved.
- Consistent patterns in the retrospective analysis. No model showed consistence in the retrospective trends.
- Realistic production curve: In many cases the production curve was not realistic.
- Checking that the same parameter estimates are obtained if using different initial values. For each run 20 different trials were fitted but in many cases with different initial values models did not converged.
- High assessment uncertainty can indicate a lack of contrast in the input data or violation of the ecological model assumptions. The main variance parameters (logsdb, logsdc, logsdi, logsdf) should not be unrealistically high. Confidence intervals for B and F should not span more than 1 order of magnitude. In all cases the confidence intervals of F span more than 1 order of magnitude.

14.4 Future considerations/recommendations

The SPiCT could be a good option in the future when a large time-series will be available.

14.5 Reviewers report

Reviewers report is only provided for the stocks that were considered for the assessment benchmark meeting (15–19 February 2021).

14.6 References

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15 Recommendations for improving the guidance and training for the application of SPiCT and for deriving MSY advice (ToR 6)

(Max, Henning, Casper and Alex to provide text)

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Paul Bouch	Marine Institute	Ireland	paul.bouch@marine.ie	X		X
Max Cardinale External Chair	Swedish University of Agricultural Sciences Dept of Aquatic Resources	Sweden	massimiliano.cardinale@slu.se	X	X	X
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Paul Coleman	Marine Institute	Ireland	paul.coleman@marine.ie	X	X	X
Anne Cooper	International Council for the Exploration of the Sea-ICES	Denmark	anne.cooper@ices.dk	X	X	X
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Ruth Fernandez	International Council for the Exploration of the Sea-ICES	Denmark	ruth.fernandez@ices.dk	X	X	
Raphael Girardin	Ifremer	France	raphael.girardin@ifremer.dk		X	
Hege Øverbø Hansen	Institute of Marine Research	Norway	hege.oeverboe.hansen@hi.no	X		X

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Teresa Moura	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal	tmoura@ipma.pt	X	X	X
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Barbara Serra Pereira	Portuguese Institute for the Sea and the Atmosphere-IPMA	Portugal	bpereira@ipma.pt	X	X	X
John Gabriel Ramirez	Galway-Mayo Institute of Technology-GMIT	Ireland	John.ramirez@gmit.ie			X
Paz Sampedro	The Spanish Institute of Oceanography-IEO	Spain	paz.sampedro@ieo.es	X	X	X
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name	institute	country	e-mail	Learning Session	Data Evaluation meeting	Assessment Benchmark
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Annex 2: Workshop agenda

http://community.ices.dk/ExpertGroups/benchmarks/2021/wkspict/SitePages/HomePage.aspx

Chairs: Manuela Azevedo, Portugal (ICES Chair) and Massimiliano Cardinale, Sweden (External Chair)

Invited Experts: Casper Berg, Denmark and Henning Winker, Italy

Data Evaluation: 17–19 November 2020 (online)

Draft Agenda (timetable = Copenhagen time)

17 November (Tuesday)

09:00–09:10

- Introductions, CoC & meeting ToRs.

09:10–10:40

Presentations, Discussion and Recommendations:

- **Dab** (*Limanda limanda*) in Subarea 4 and Division 3.a (**dab.27.3a4**)
- **Flounder** (*Platichthys flesus*) in Subarea 4 and Division 3.a (**fle.27.3a4**)

10:40–11:00 Health break

11:00–13:00

- **Tusk** (*Brosme brosme*) in subareas 1 and 2 (**usk.27.1–2**)
- **Tusk** (*Brosme brosme*) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (**usk.27.3a45b6a7-912b**)
- **Megrim** (*Lepidorhombus* spp.) in Division 6.b (Rockall) (**lez.27.6b**)

18 November (Wednesday)

09:00–10:40

Presentations, Discussion and Recommendations:

- **Cod** (*Gadus morhua*) in Division 7.a (Irish Sea) (**cod.27.7a**)
- **Sole** (*Solea solea*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (**sol.27.8c9a**)

10:40–11:00 Health break

11:00–13:00

- **Black-bellied anglerfish** (*Lophius budegassa*) in divisions 8.c and 9.a (**ank.27.8c9a**)
- **Pollack** (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (**pol.27.89a**)

19 November (Thursday)

09:00–10:40

- **Norway lobster** (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and northern Galicia) (**nep.fu.25**)
- **Norway lobster** (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay and Cantabrian Sea) (**nep.fu.31**)

10:40–11:00 Health break

11:00–12:30

- **Norway lobster** (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (**nep.fu.2627**)
- **Norway lobster** (*Nephrops norveg*icus) in Division 9.a, Functional Units 28–29 (Atlantic Iberian waters East and southwestern and southern Portugal) (**nep.fu.2829**)
- **Irish Sea cod–**exploratory assessment run with SS3 & comparison between JABBA & SPiCT assessments

12:30–13:00

Summary of recommendations and work planning for the February 2021 benchmark

Assessment benchmark: 15–19 February 2021 (online)

Agenda (timetable = Copenhagen time)

15 February (Monday)

09:00–09:05

- Introductions & CoC.

09:05–11:05

Presentations (15 min/Stock), Discussion and Recommendations/Conclusions:

- **Tusk** (*Brosme brosme*) in subareas 1 and 2 (**usk.27.1–2**).
- **Tusk** (*Brosme brosme*) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (**usk.27.3a45b6a7–912b**).

11:05–11:35 Health break

11:35–12:35

- **Megrim** (*Lepidorhombus spp*.) in Division 6.b (Rockall) (**lez.27.6b**).

12:35–14:00 Lunch break

14:00–16:00

- **Black-bellied anglerfish** (*Lophius budegassa*) in divisions 8.c and 9.a (**ank.27.8c9a**).
- **Pollack** (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (**pol.27.89a**).

16 February (Tuesday)

09:00–10:30

Presentations (15 min/stock), Discussion and Recommendations/Conclusions:

- **Norway lobster** (*Nephrops norveg*icus) in Division 9.a, Functional Units 28–29 (Atlantic Iberian waters East and southwestern and southern Portugal) (**nep.fu.2829**)

10:30–11:30 Health break

11:30–12:30

- **Norway lobster** (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and north Galicia) (**nep.fu.25**)
- **Norway lobster** (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay, Cantabrian Sea) (**nep.fu.31**)

12:30–14:00 Lunch break

14:00–16:00

- **Norway lobster** (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (**nep.fu.2627**)
- **Megrim**–extra SPiCT assessment runs: results and diagnostics.
- **Black-bellied anglerfish**–extra SPiCT assessment runs: results and diagnostics.

17 February (Wednesday)

09:00–12:30

- **Norway lobster FU28–29**–extra SPiCT runs: results and diagnostics
- **Norway lobster FU25**–extra SPiCT runs: results and diagnostics
- **Norway lobster FU31**–extra SPiCT runs: results and diagnostics
- **Norway lobster FU26–27**–extra SPiCT runs: results and diagnostics
- **Pollack**–Selection of a reference fleet for Pollack: ROMELIGO project.
- **Tusk** in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b NEA – revisiting SPiCT assessment runs.
- **Subgroup:** extra SPiCT runs for Nep FU28–29

12:30–14:00 Lunch break

14:00-16:00

- **Norway lobster FU25**–extra SPiCT runs: results and diagnostics.
- **Norway lobster FU31**–extra SPiCT runs: results and diagnostics.
- **Norway lobster FU28-29**–extra SPiCT runs: results and diagnostics.
- **ToR 4**–options for the catch forecast for stocks with SPiCT accepted assessments

18 February (Thursday)

10:00–12:00

- **Megrim**–catch forecast
- **General recommendations**

19 February (Friday)

10:00–12:00

- **Black-bellied anglerfish**–catch forecast
- **Megrim**–catch forecast
- **Norway Lobster FU 25**–Estimates and diagnostics for extra run
- **Norway Lobster FU 31**–catch forecast
- **Norway Lobster FU 26–27**–catch forecast

13:00–14:00 Lunch break

14:00–15:30

- **Norway Lobster FU 25**–Estimates and diagnostics for new run
- **Norway Lobster FU 31**–catch forecast
- **Norway Lobster FU 26–27**–catch forecast
- **Black-bellied anglerfish**–catch forecast

Annex 3: List of tasks by stock

WKMSYSPiCT Data Evaluation Workshop

Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (dab.27.3a4)

- Investigate extending the delta-GAM index with Belgian and German BTS data (prior to 2002).
- Investigate the inclusion of additional survey information, e.g. IBTS Q1 and Q3, DYFS, SNS.
- Investigate inclusion of reconstructed historic catch data (before 2002)
- Investigate if priors should be used/changed; sensitivity analysis

Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (fle.27.3a4)

- Investigate the inclusion of additional survey information, DYFS Q3
- try different uncertainties also on survey indices and use longer time-series of Q3 index
- try different priors on B/K; sensitivity analysis
- provide sensitivity analysis on prior sd log(n)

Tusk (*Brosme brosme*) in subareas 1 and 2 (usk.27.1–2)

- Keep both targeted and all data CPUE
- Insert the longer time-series on landings
- Due to left skewed production curve; try stronger prior on n (n=2?)
- When having longer time-series on landings; try prior on B/K≈1

Tusk (*Brosme brosme*) in subareas 4 and 7–9, and in divisions 3.a, 5.b, 6.a, and 12.b (usk.27.3a45b6a7–912b)

- Keep both targeted and all data CPUE
- Insert the longer time-series on landings
- Delete year 2010 from CPUE
- When having longer time-series on landings; try prior on B/K≈1
- Put priors on n (use same prior for both stocks); n=2?

Megrim (*Lepidorhombus spp.*) in Division 6.b (Rockall) (lez.27.6b)

- Investigate adding the additional survey indices currently applied in the 4a6a assessment
- Evaluate adding ICES historic data to catch series
- Investigate if survey is sampling the exploitable biomass; check similarity in size distribution between survey and catch, are they similiar
- Check that the time factor for the survey is correct
- Survey index; std dev should not be used, use log instead

Cod (*Gadus morhua*) in Division 7.a (Irish Sea) (cod.27.7a)

- Investigate using longer catch series from 1903
- Investigate the use of priors on K
- Check the use of JABBA

- Some of the issues regarding the stock structure and recent changes in fishery, migratory behaviour and reduced spawning are difficult to reflect in production model, giving advice is difficult.
- Try Stock Synthesis which looks more promising as significant data are available and stock synthesis does not require natural mortality or recruitment input.
- Explore SPiCT by considering regime shift; approach with time-variant productivity

Sole (*Solea solea*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters) (sol.27.8c9a)

Next steps:

- Finalize LPUE for the Portuguese fleet and trying to introduce this index in the model;
- Applying spatio-temporal models to surveys index;
- Sensitivity analysis for priors of log_bkfrac and log_n

Comments and suggestions:

- Testing different scaling effect for catches, especially in the first years of the time-series. Also, data from 1903–1950 are present in the historical ICES database for *S.solea*. Although this dataset could have some problem of misidentification among all species sole could be used as SPiCT can manage Na values in the catches time-series.
- Applying a combined spatio-temporal model for both surveys indices for Portugal and Spain;
- Mapping not only the surveys data but also data from fishery if possible, for the all sole species in order to understand if there exists a spatial segregation in habitat for these species and there is a spatial overlap between surveys data and the fishery footprint.

Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (ank.27.8c9a)

Next steps:

- Finalize CPUE standardization for the Portuguese OTB fleets

Comments and suggestions:

- Work on a combined index including all the fleets (spatial model or weighted average)
- Check the utility of historical data (prior to 1978) –to overcome the issue of misidentification in landings, the proportion of each species (white and black anglerfish) along time can be assessed

Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) (pol.27.89a)

- To update the model with year 2019. Although not major differences are expected.
- The Base Case results are sensitive to priors used.
- The convergence is only achieved assuming strong priors for B/K. Is there additonal information to guide on fracB/K?
- Investigate the use of historical catches available at ICES.

Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and north Galicia) (nep.fu.25)

Next steps:

- Check Survey index calculate procedure

- Present mean sizes of survey and fishery
- Forecast of the different runs
- Priors for B_{MSY}/K and input$priors$logsdf=c(log(3), 0.2, 1)

Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal) (nep.fu.2627)

Next Steps:

- Work on a combined survey index from Spanish and Portuguese surveys. Outliers analysis.
- Applying a spatio-temporal model for Spanish and Portuguese surveys
- Use stronger priors of log_bkfrac and log_n

Norway lobster (*Nephrops norveg*icus) in Division 9.a, Functional Units 28–29 (Atlantic Iberian waters East and southwestern and southern Portugal) (nep.fu.2829)

Next steps:

- Finalize the CPUE standardization for Norway lobster in FU 28–29
- Update the SPiCT model with the new standardized CPUE time-series

Comments and suggestions:

- Use a cluster-based covariate as a proxy of target and non-target fishing in the CPUE model
- Investigate and improve the spatial component of the model

Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay, Cantabrian Sea) (nep.fu.31)

Next steps:

- Check Survey index calculate procedure
- Present mean sizes of survey and fishery
- Apply prior input$priors$logsdf=c(log(3), 0.2, 1)
- Apply JABBA model